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An application of LIDAR to examine erosion in the southern Monterey Bay during the 1997-98 El Nino

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN APPLICATION OF LIDAR TO EXAMINE EROSION IN THE SOUTHERN MONTEREY BAY DURING THE 1997-98 EL NINO

by

Lora A. Egley

March 2002

Thesis Advisor:	Edward B. Thornton
Thesis Co-Advisor:	Arthur R. Parsons

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Light Detection and Ranging (LIDAR) was used in a Geographic Information System (GIS) to quantify coastal changes to beaches and dunes in the Southern Monterey Bay region and to qualitatively assess the erosional impact of large storms on coastal dune areas. LIDAR provides a rapid and accurate survey technique to measure topographic elevation. A LIDAR survey was performed in October 1997 and then a second survey in April 1998 to measure the erosion occurring during the 1997-1998 El Niño winter storm. Maximum dune erosion occurred in the vicinity of Fort Ord (13 m) and Marina (15 m), along with significant dune recession in Monterey and Sand City. Beach erosion was prevalent from Moss Landing to Monterey showing the seasonal beach loss. There was a large spatial variability all along the shoreline, with many numerous erosional "hot spots". From the profile data, the calculated volume loss from Monterey to Moss Landing (~22 km) was 880,800 m^3, which was calculated by multiplying the dune top recession between the two surveys by the height of the dune from the toe to the dune top. From the cut fill calculation within ArcView total volume loss was calculated to be 2,470,000 m^3, which included both dune and beach erosion. LIDAR data provide a high-quality representation of the episodic erosion process in Southern Monterey Bay, and also offers useful environmental information to the warfighter in terms of detailed beach or landing zone characterizations.

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AN APPLICATION OF LIDAR TO EXAMINE EROSION IN THE SOUTHERN MONTEREY BAY DURING THE 1997-98 EL NINO

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ABSTRACT

Light Detection and Ranging (LIDAR) was used in a Geographic Information System (GIS) to quantify coastal changes to beaches and dunes in the Southern Monterey Bay region and to qualitatively assess the erosional impact of large storms on coastal dune areas. LIDAR provides a rapid and accurate survey technique to measure topographic elevation. A LIDAR survey was performed in October 1997 and then a second survey in April 1998 to measure the erosion occurring during the 1997-1998 El Niño winter storm. Maximum dune erosion occurred in the vicinity of Fort Ord (13 m) and Marina (15 m), along with significant dune recession in Monterey and Sand City. Beach erosion was prevalent from Moss Landing to Monterey showing the seasonal beach loss. There was a large spatial variability all along the shoreline, with many numerous erosional "hot spots". From the profile data, the calculated volume loss from Monterey to Moss Landing (~22 km) was 880,800 m^3, which was calculated by multiplying the dune top recession between the two surveys by the height of the dune from the toe to the dune top. From the cut fill calculation within ArcView total volume loss was calculated to be 2,470,000 m^3, which included both dune and beach erosion. LIDAR data provide a high-quality representation of the episodic erosion process in Southern Monterey Bay, and also offers useful environmental information to the warfighter in terms of detailed beach or landing zone characterizations.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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EXECUTIVE SUMMARY

Widespread coastal beach and dune changes occurred during winter storms of the 1997-1998 El Niño. Three government agencies; US Geological Survey (USGS), National Aeronautics and Space Administration (NASA) and National Atmospheric and Oceanic Administration (NOAA) worked in partnership to quantify these coastal changes using Airborne Topographic Light Detection and Ranging (LIDAR). The LIDAR technique offers rapid acquisition of elevation data along with a vertical accuracy of less than 20 cm and a horizontal pixel size of 2 m.

The focus of this study is to calculate the erosion in the Southern Monterey Bay region utilizing LIDAR in a Geographic Information System (GIS). ArcView was the tool that enabled one to map, model, query, and analyze the elevation data. Then a. quantitative and qualitative assessment of the erosional impact of large storms on coastal dune areas could be done. Recession, accretion, and volume losses or gains were calculated.

The calculated dune top recessions ranged from 0 m to 17 m along the Southern Monterey Bay coastline. The volume loss calculated from the dune top cross profiles was determined to be 1,260,300 m^3. The total beach and dune loss was calculated to be 3,423,656 m^3. Highest recessions occurred along the Fort Ord and Marina shoreline.

Additionally, military applications for LIDAR are abundant. For example, with the assistance of LIDAR, this environmental information can improve the decision making process in amphibious operations and beach landings. In particular, safe routes can be planned through beach characterization for U.S. military vehicles.

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I. INTRODUCTION

US Geological Survey (USGS), National Aeronautics and Space Administration (NASA) and National Atmospheric and Oceanic Administration (NOAA) collaborated to measure coastal change using Airborne Topographic LIDAR with the intent to survey pre and post storm topography. Rapid acquisition and high density data are key advantages LIDAR surveys have over the traditional survey methods. Sallenger et. al. (2001b) discuss the Airborne Topographic Mapper (ATM) for coastal mapping and distinguishes the ability LIDAR to detect a variety of situations such as overwash areas, dune erosion and accretion, landslides, and longshore sediment transport (USGS 1999b).

Erosion in Southern Monterey Bay was measured using LIDAR (Light Detection and Ranging) as the survey method. There have been several traditional surveys within the Monterey region, but nothing as dense and detailed as the LIDAR technique. Current research emphasis is placed on examining coastal change to determine the magnitude of this change with respect to sediment volume transport, recession and accretion rates. This chapter provides motivation for the study, research objectives, and background on previous erosion studies.

LIDAR provides a rapid and accurate survey technique to measure topographic elevation and bathymetry in coastal waters. LIDAR can be a valuable resource to the Navy's operational oceanographer in providing environmental and intelligence information to operational units. Beach and coastal regions can be characterized with a vertical accuracy of 20 cm, which could aid in planning for amphibious landings and special operations. Beach characterization, detailed coastal bathymetry, underwater hazards, and bottom type are some of the operational products that LIDAR can provide to the warfighter. LIDAR technology therefore can assist the Navy and Marine Corps in littoral operations by enhancing battle space information that provides near real time observations for unfamiliar surroundings or settings that may have changed over time.

Commercial applications of LIDAR are numerous with respect to environmental monitoring and land use. It can assist in providing a scientific understanding and foundation needed to develop and implement technically sound land use planning

solutions. Furthermore, storms cost millions of dollars in damage to public park facilities, businesses, and homes, therefore applying LIDAR technology can aid in predicting high risk areas. Sediment transport, seasonal and long term erosion, and mapping flood prone areas are just a few coastal LIDAR applications.

The objective of this study is to quantify coastal changes to beaches and dunes in the southern Monterey Bay region utilizing LIDAR survey data during the 1997-1998 El Niño winter. The aim is to apply LIDAR data in a Geographic Information System (GIS), which will enable to quantitatively assess the erosional impact of large storms on coastal dune areas through mapping, modeling, querying and analyzing the data. ArcView was the selected GIS software to use, developed by Environmental Systems Research Institute (ESRI 2002).

A. BACKGROUND

Southern Monterey Bay shoreline from Monterey to Moss Landing examined, which is characterized by extensive sand dunes rising up to a high as 46 m in the Fort Ord and Marina area. The mechanisms for potential losses and sources of sand were depicted by Galliher (1932) for Southern Monterey Bay shown in Figure 1. Probable mechanisms for loss of sand are Monterey Submarine Canyon, dunes formed by winds, damming of Salinas River, past sand mining, and seawalls/riprap. Sources of sand to the beaches are the erosion of dunes and Salinas river discharge. Erosion is defined here as a recession of the top of the dune as this is the seaward extent of functional land use and because of the prevailing onshore winds, there is no mechanism to build out the dune top. Erosion events are episodic and occur when storm waves and high tides occur simultaneously resulting in the base of the sand dune being cutback and slumping causing permanent recession of the dune.

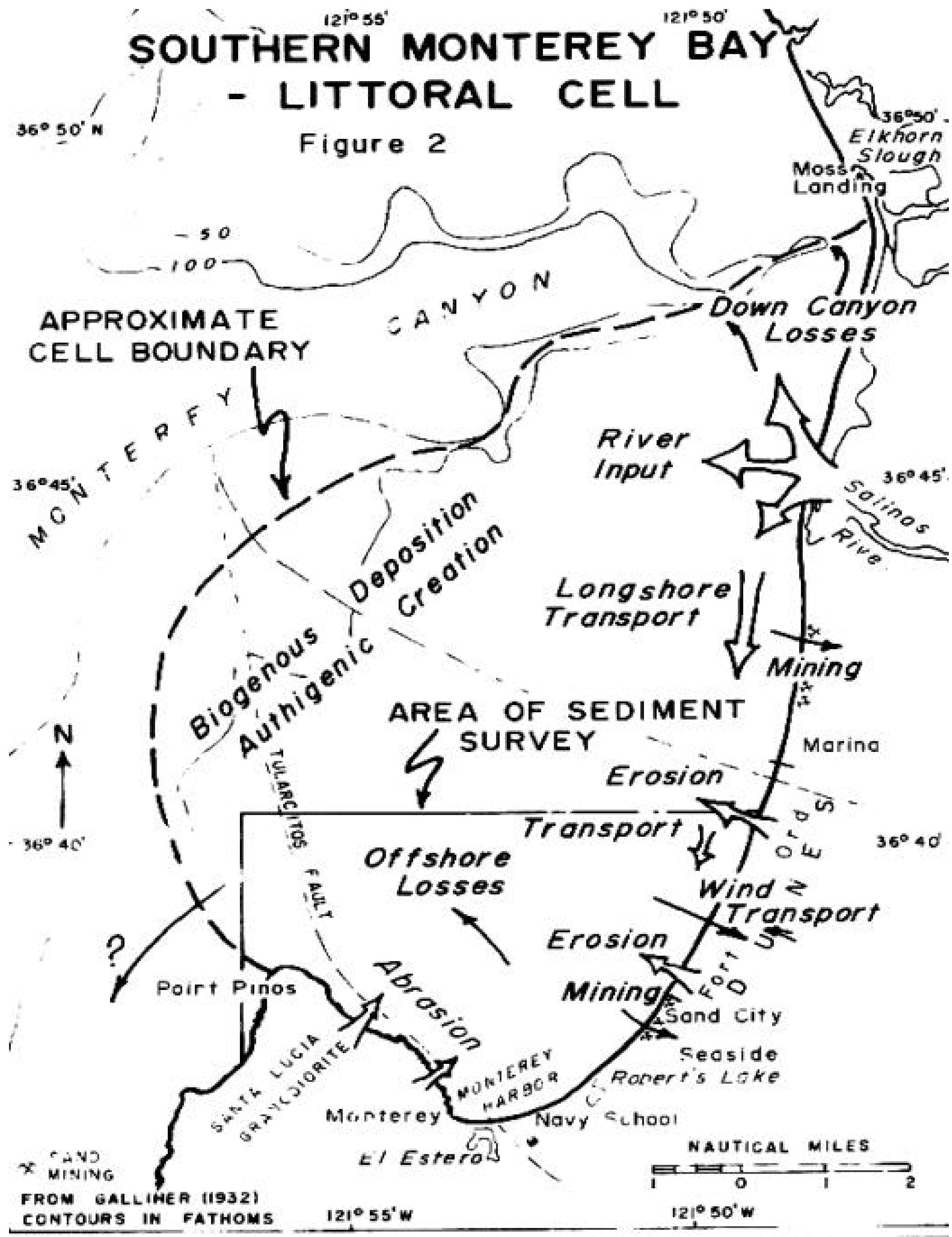

Figure 1. Southern Monterey Bay Sand Sources and Losses (from Dorman 1968)

1997-1998 was a strong El Niño winter. Storlazzi and Griggs (1998) characterized the 1997-98 El Niño Southern Oscillation (ENSO) in terms of weak easterly trade wind, anomalously high sea surface temperatures, high sea level elevations, large rainfall, and large waves for the central California coast. They found maximum

monthly mean significant wave height from 1987-1997 did not exceed 2 m in northern Monterey Bay. However, the nearshore significant wave heights exceeded 2 m starting in late November 1997, with a peak in February 1998 that exceeded 4.2 m in the northern Monterey Bay. Flick (2001) found the incident wave direction was more westerly wave directions during this period based on Coastal Data Information Program (CDIP). Flick (2001) used cumulative precipitation in Monterey as a gauge to specify storminess. The average annual rainfall is 50.8 cm (20 inches) per year. During the 1997-98 winter, the most rainfall occurred for the past 50 years (Figure 2).

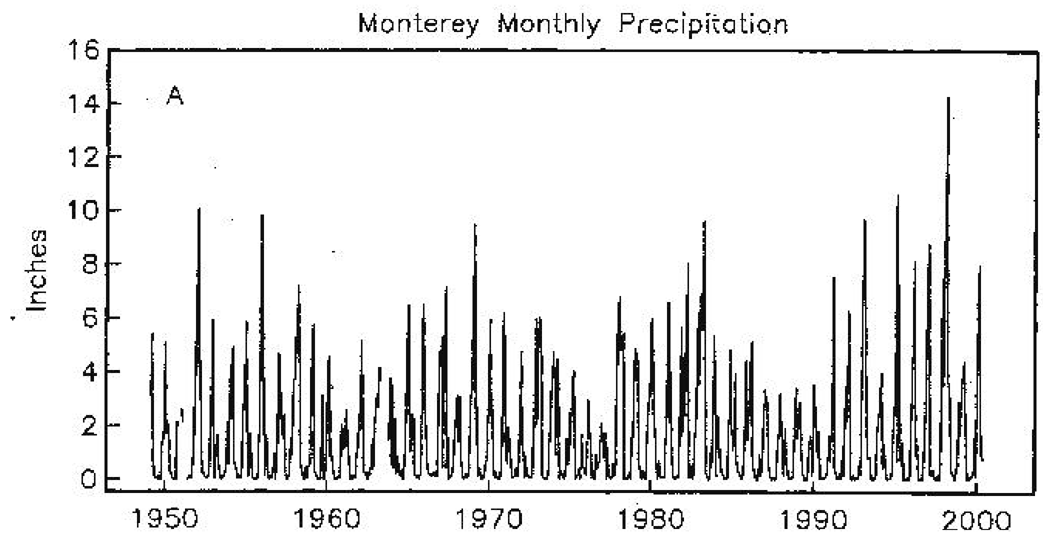

Figure 2. Monterey Monthly Precipitation (from Flick 2001).

The potential for erosion to occur increases with tide level. Flick (1998) hypothesized that anomalously high tides occur during El Niño events due to warm water along the coast. He examined the tides at San Francisco to characterize the tides for central California. A peak tide of 2.1 m occurred in December of the 1997-1998 El Niño with above average mean water levels in the fall of 1997. He found record high mean sea levels (msl), .06 m to .37 m above normal (Figure 3). Furthermore, the coast endured a large storm surge of 0.98 m in February 1998 (Figure 4).

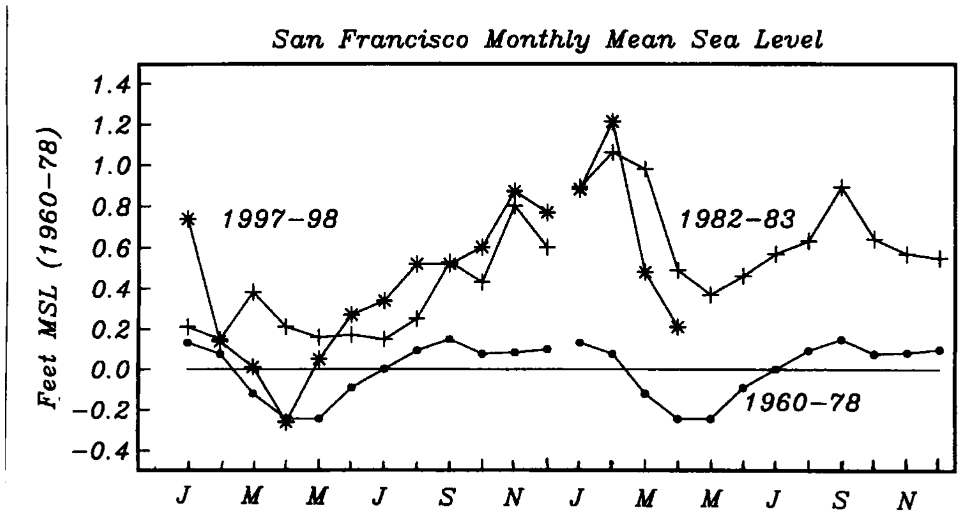

Figure 5. Monthly mean sea levels at San Francisco, winters of 1982-83 and 1997-98 compared with the mean values over the 1960-78 tidal datum epoch.

Figure 3. San Francisco Monthly Mean Sea Levels (from Flick 1998).

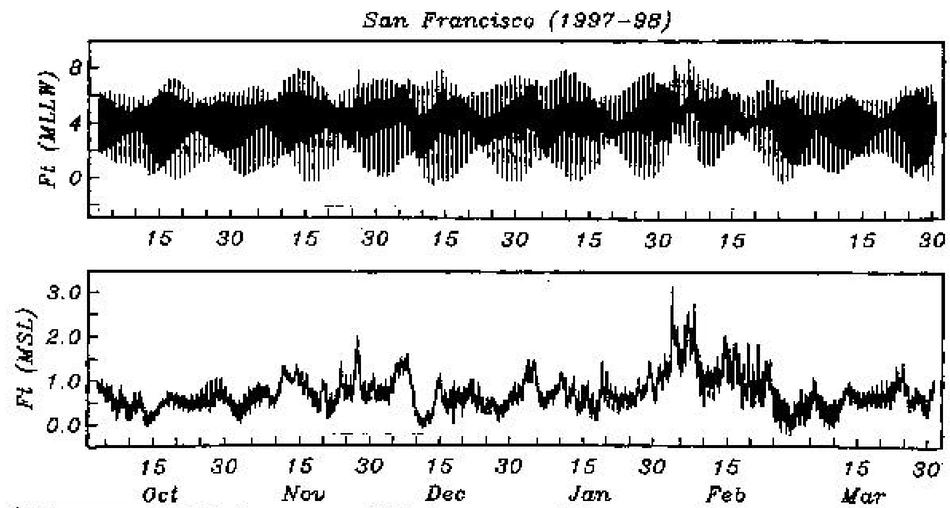

Figure 2. Measured hourly water level (upper) and storm surge (lower) at San Francisco from October 1997 to 31 March 1998.

Figure 4. San Francisco Monthly Mean Sea Levels (from Flick 1998)

Seymour (1998) examined the relationship between large wave events and El Niños utilizing wave data from the CDIP wave height archives along the west coast. A storm was defined as occurring when the significant wave height exceeded 4 m for 9 hours or more. A correlation of storms occurrence with El Niño was shown in the southern California region, but not in the Northwest coasts of Oregon and Washington. Southern California experienced large wave events in 1998.

A number of erosion studies have been conducted for Southern Monterey Bay using photogrammetric methods. The studies by Sklavidis and Blanco (1985) and McGee (1986) performed stereo-photogrammetry on 5 sets of aerial photos from 1940 to 1984 to measure cliff recession along the Southern Monterey Bay shoreline. The studies showed general recession of the shoreline, with the exception of Moss Landing area where net accretion has occurred. The measurements show the erosion rate is variable from year to year.

The results of these studies along with descriptions provided by Griggs and Savoy (1985) based on historical photos are used to give a history of particular sites (Figure 5). Starting at the north and proceeding south, Moss Landing is observed to dominantly undergo beach accretion, with an average .6 m/yr accretion rate from 1937 to 1983 (Griggs and Savoy 1985). However, they did note a case of episodic erosion in 1982-1983, coinciding with a strong El Niño winter with a 5.2 m dune recession near the Marine Lab. McGee (1986) found similar average 0.45 m for the period 1944-1984 at the old Marine Lab.

Southern Monterey Bay

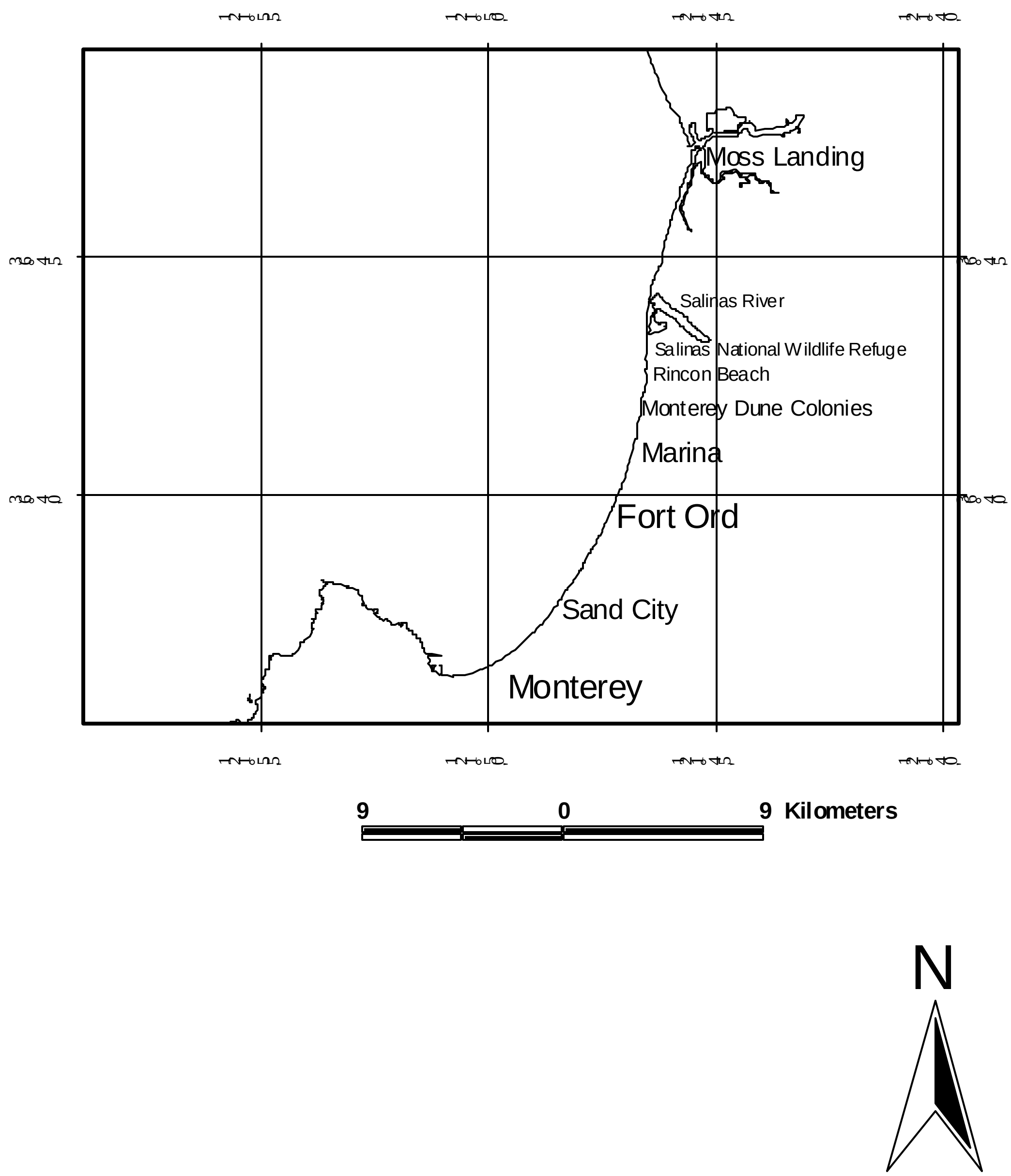

Figure 5. Southern Monterey Bay

Mean recession at Rincon Beach was 0.84 m/yr (McGee 1986) with up to a 30 m cutback of dunes occurred between 1978-1983 in the Monterey Dunes Colonies next door (Griggs and Savoy 1985). The mean recession rate at Marina State Beach was 0.4 m/yr (McGee 1986). Increased recession of 2.1 m/yr, occurred 1980-1984, which included a

strong El Niño year and an extreme event in 1978 that took out 24 m of dune (Griggs and Savoy 1985).

The highest erosion rate occurs in Fort Ord region with a specific site losing up to 12 m erosion in 1983 (Griggs and Savoy 1985). The average recession rate of 1.83 m per year was found by Sklavidis and Blanco (1985). McGee (1986) calculated 1.12 m/yr recession rate from 1944-1984, as well as a 3.85 m/yr recession rate during 1980-1984. McGee (1986) states that the energy convergence from refractive wave focusing is one of the probable sources of high erosion rates occurring in the area.

In Sand City, Sklavidis and Blanco (1985) reported a 1.5 m to 2.7 m per year at the Phillips Petroleum site. McGee (1986) calculated give recession rates of 0.97 m/yr during 1940-1984 and 1.34 m/yr during 1980-1984 for Sand City.

Griggs and Brown (1998) provide a descriptive assessment of the damage incurred during 1982-83 and 1997-98 ENSO winters along the central California coastline and compare the two events. During the 1982-83 ENSO, extensive damage was shown in terms of substantial property and infrastructure damage. The 1997-98 ENSO was noted with less damage, which was attributed to post 1982-83 ENSO seawall and revetments. Of particular interest for this study, is the Monterey City beach was depicted in the article showing the temporary riprap that was placed in front of an apartment complex in 1982. This riprap was later removed in 1992. The apartments survived the 1998 large waves, but there was significant erosion in the surrounding area, which is evident from photographs.

Dingler and Reiss (2001) investigate changes to Monterey Bay shoreline from 1982-1998 by way of traditional survey methods for nine beaches in Monterey Bay. They showed for a selected Fort Ord site that the there was a 21 m retreat in the 16 years and state most of the erosion occurred during the El Niño events of 1982-1983 and 1997-1998. Dingler et. al. (1985) showed beaches eroding then recovering, but noting each has its own unique rebuild pattern.

II. LIDAR MEASUREMENTS

A. AIRBORNE TOPOGRAPHIC MAPPER (ATM)

The objective is to analyze LIDAR data in conjunction with aerial oblique photos and digital orthophoto quadrangles to assess changes in the beaches and dunes qualitatively and quantitatively. To help in the analysis ArcView Spatial analyst tools are utilized to create slope, aspect, difference, and volume loss or gain maps.

ATM was flown along the shoreline of Monterey Bay in October 1997 and April 1998. The 1997 LIDAR data were collected during low tide on October 12 and 13 and the 1998 LIDAR data were collected on April 15,17, and 18 during low tide. The LIDAR 1997 coverage is shown in Figure 6. The scan width of the ATM's is approximately 300 m with an aircraft elevation of 700 m (Figure 7). A flowchart of how the elevation files are generated in the ATM System are shown in Figure 8 (NOAA 2001). The ATM system combined with the Global Positioning System (GPS) and inertial navigation to determine the range of the laser and trajectory of the aircraft.

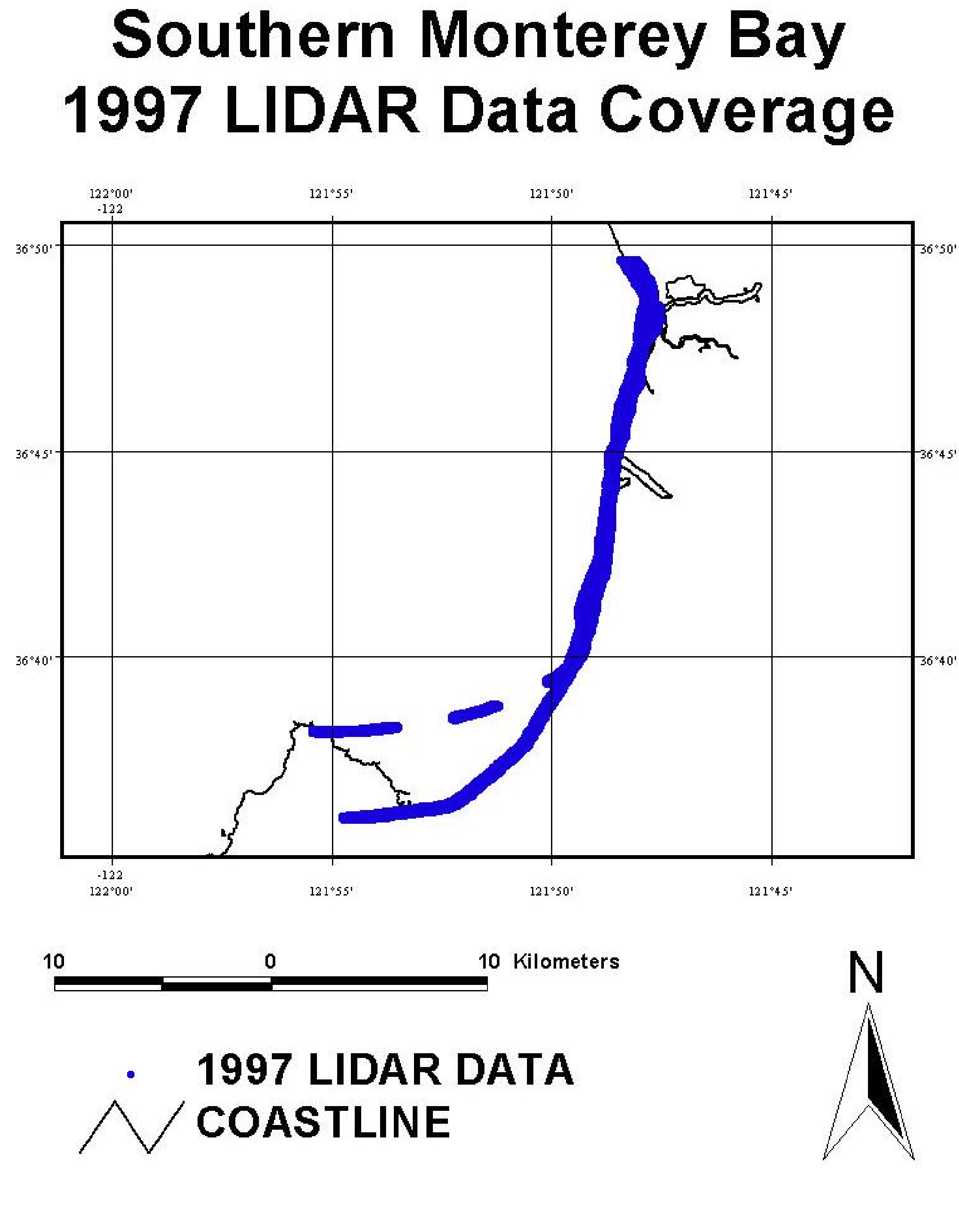

Figure 6. 1997 LIDAR Data Coverage

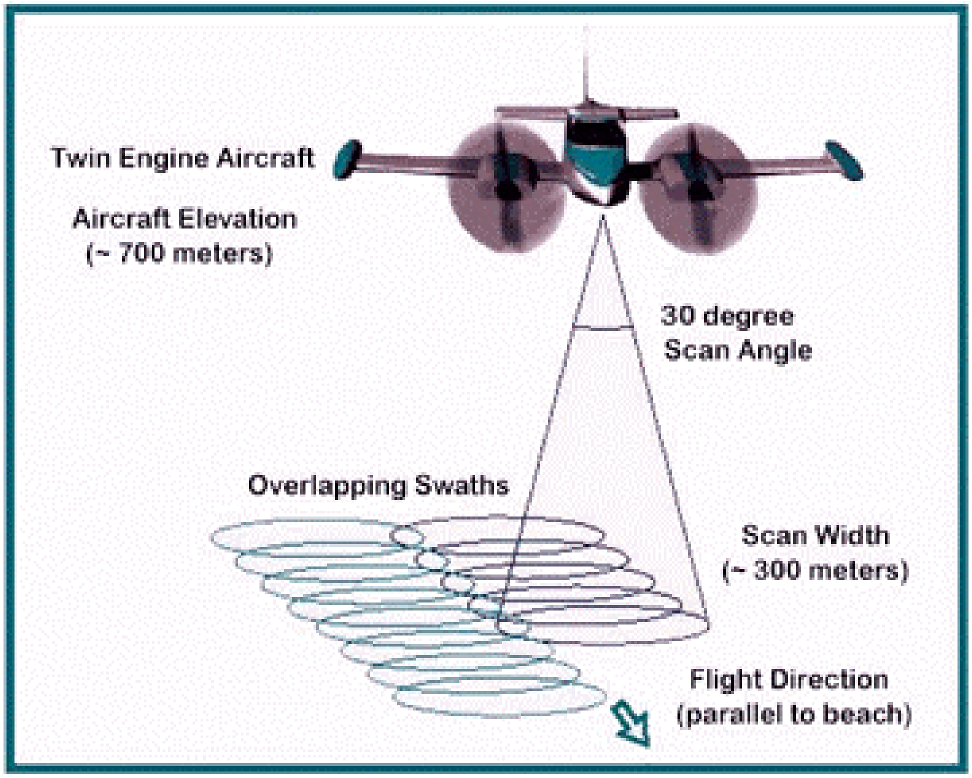

Figure 7. Airborne LIDAR Mapping (from NOAA 2001)

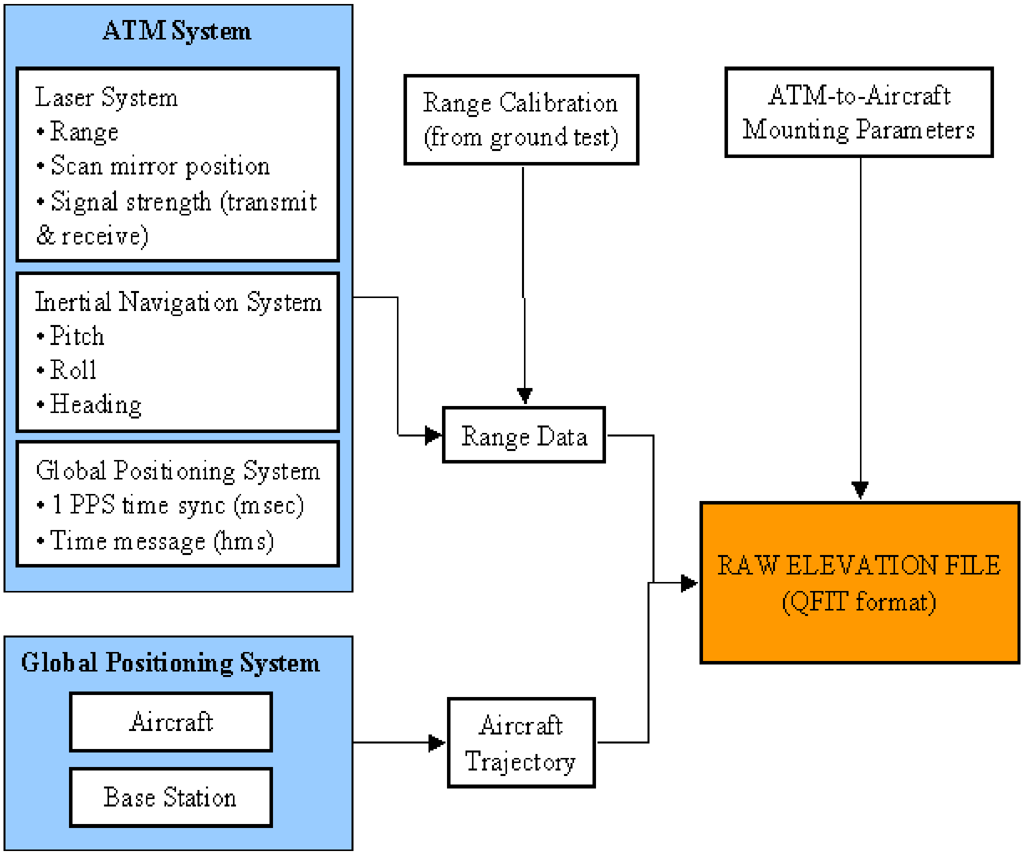

Figure 8. Generation of Elevation files (from NOAA 2001).

The ATM provides a vertical accuracy of 15 cm and a horizontal resolution of at least 2 m. System spatial errors are collected using the GPS, calculated panoramic distortion and scan rate. Brock et. al. (1999) state the spatial density of the elevation measurements occur every 2 m^2. To get this accuracy the aircraft's GPS antenna must be known to approximately 5 cm (Krabill and Martin 1987) and the ATM must be calibrated. Meridith et. al. (1998) discuss the calibration requirements of the ATM, which include a corrections for the laser range and angular mounting biases with respect to the aircraft attitude. They state for a tenth of a degree mounting error a 32 /cm vertical error with a 131 /cm horizontal error would be introduced. The aircrafts attitude and position use kinematic GPS techniques, therefore satellite availability along with a their associated geometry are sources of errors (Krabill et. al. 1995). There is some variability in the altitude the plane is flying, along with variable swath overlap, which is typically 30 percent (Meredith et. al. 1998). The ATM has a 2.1 milliradian field of view and its scan

mirror rotates at 20 Hz along with a 15 degree off nadir angle. Increasing scan distance (or scan angle) from nadir translates to a larger pixel dimension. Overlapping the track can solve this panoramic problem. We need small field of views to see detail. Equation

Distance of one side of a pixel, D, is given by

$$D = HB$$

$$D = 700\,m * .0021\,rad = 1.47\,m$$

and the swath widt h, S, is given by

$$S = 2(\tan\frac{q}{2})H$$

$$S = 2(\tan\frac{15}{2})700\,m = 374.93\,m$$

where H is the sensor height and b is the field of view.

giving the distance of one side of a pixel and the swath distance is given below.

Meridith et al. (1998) provided a comparison and a validation of the ATM with extensive ground surveys points on the North Carolina coast. LIDAR measurements were compared with ground surveys on different days resulting in a mean difference of 4.6 cm and a standard deviation of 8.7 cm of elevation differences. The statistics from ATM to ground survey comparisons gave a mean difference of less than 10 cm except for one which was still less than 15 cm and the root mean square (RMS) was less than 20 cm. These measurements agree with Krabill et al. (1995), who found an RMS range of 9 cm to 14 cm when comparing LIDAR with ground survey data. Therefore, the RMS error is taken to be less than 20 cm.

The Digital Orthophoto Quadrangles (DOQ's) were produced by the IntraSearch Company (2002) from black and white aerial photographs from 21 August 1998. Approximately 7 exposures were used to generate the digital imagery. The photographs were scanned at 2000 dpi with a Vexcel HT-4000 photogrammeteric film scanner to yield a .5 m pixel resolution. USGS 7.5 minute quadrangle data and USGS digital elevation model data were used as the control. Approximately 9 control points were used per exposure in the orthoretification process. The DOQ's final output was projected in UTM coordinates, and the horizontal datum NAD-83. Oblique aerial photographs were obtained from the USGS (1999). The aerial photos were taken during the LIDAR flights on October 20, 1997 and April 20, 1998.

B. DATA PROCESSING

The LIDAR data was converted to a convenient Cartesian coordinates for analysis with vertical data corresponding to a height close to mean sea level. The LIDAR data datum is the World Geodetic System 1984 (WGS-84) and was retained. However, the original geographic (geodetic) projection was changed utilizing a geographic translator (GEOTRANS) to convert geodetic coordinates to Universal Transverse Mercator (UTM) coordinates zone 11 (PAR Government Systems Corporation 1999). UTM coordinates were selected so that all x, y, z data were in meters to facilitate distance and volume calculations within ArcView. After processing data in GEOTRANS, the horizontal and vertical map accuracy achieved was 90% for circular and linear error respectively. A 90% Circular Map Accuracy means 90% of all well defined features fall within the circle size specified. A 90% linear error means that all the contours will fall within a certain contour interval. To project at a constant scale is not possible. Therefore, the scale error that is introduced is actually a systematic distortion. To preserve maximum data density ellipsoidal elevations were only tested for gross errors. Elevations less than –35 m and greater than 130 m, were removed. The data were then sorted by latitude and partitioned in to 20 regions.

The G99SSS geoid model incorporating a one by one arc minute grid was used to convert the ellipsoidal height to a value close to mean sea level called the geoid surface (global geopotential surface) (NOAA 2000). The accuracy with respect to GPS or benchmarks is 4.6 cm. The source of error is in GPS heights along with geoid and leveling errors (NOAA 2000). The relationship with respect to surfaces is shown in Figure 9. The global geopotential surface is shown in large dashes and the International Terrestrial Reference Frame (ITRF 96) as a solid black line.

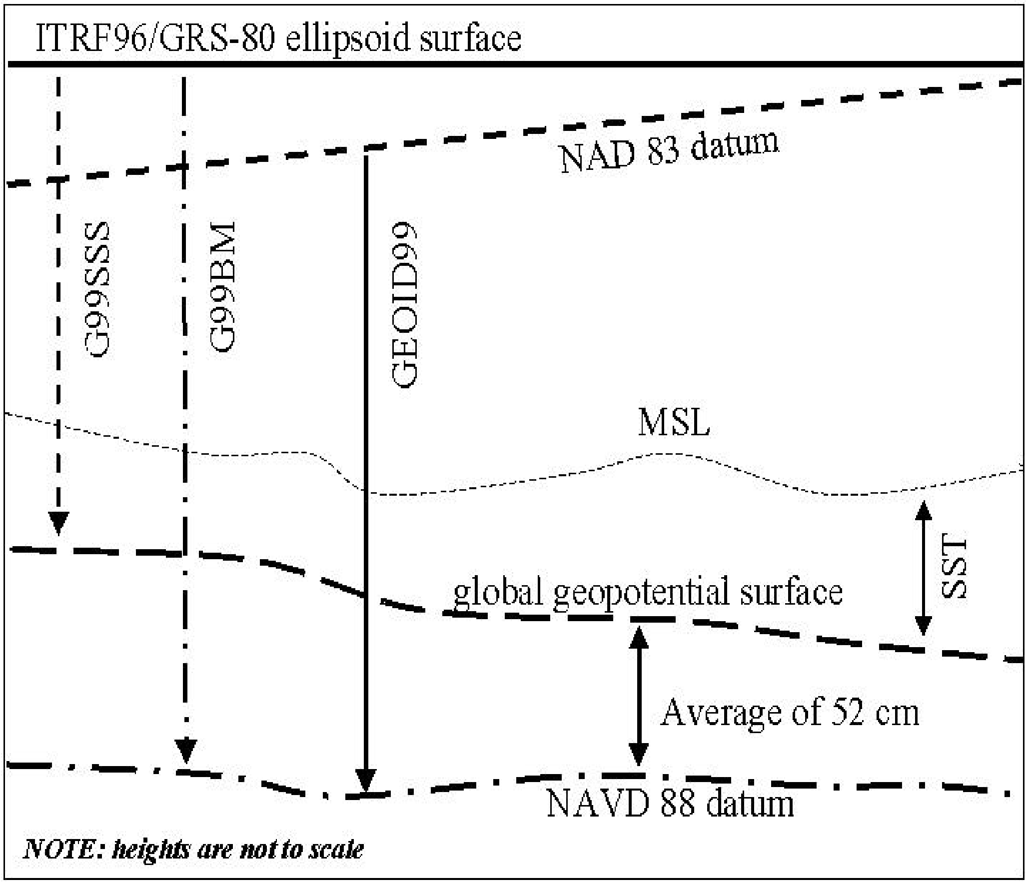

Figure 9. Height Relationships: (from NOAA 2000).

The LIDAR data were binned every .01° and an undulation was calculated for that region and applied to each ellipsoidal height. The specific global geopotential surface elevations in meters that correspond to Southern Monterey Bay's Northing that were used in this study are given in Figure 10 and Table 1. The global geopotential surface represents elevation in meters through out this study.

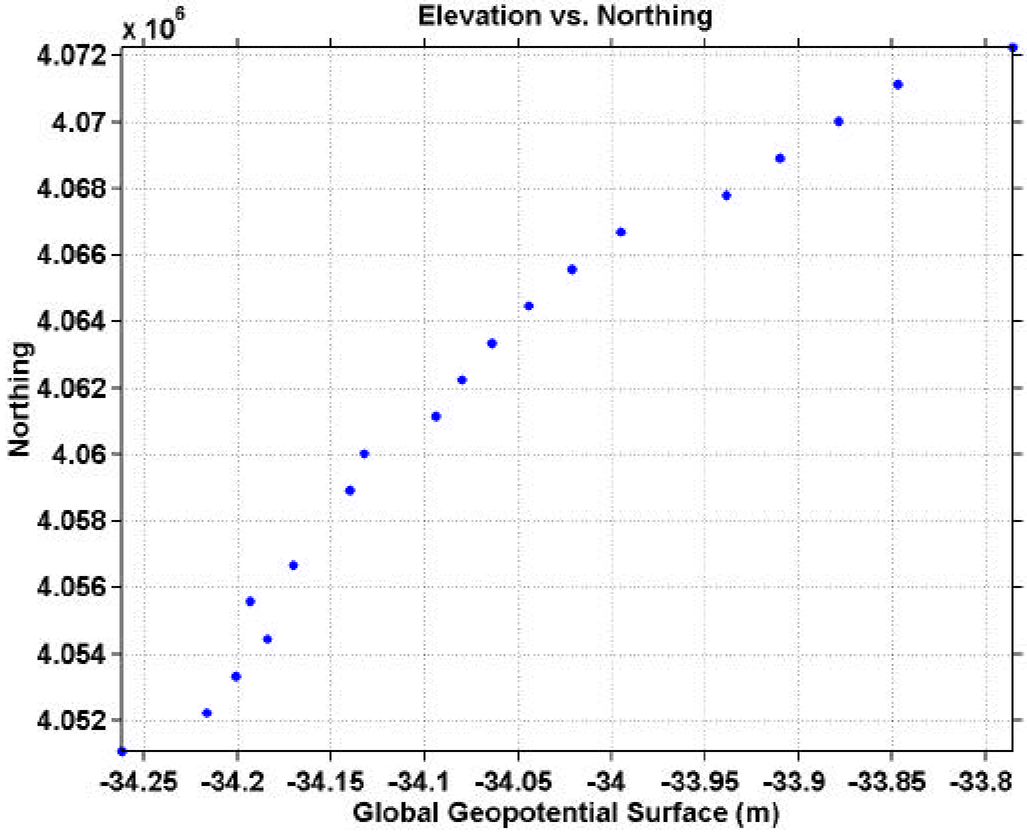

Figure 10. Global Geopotential Surface with respect to Northing

Bin File	Northing	Latitude	Global Geopotential Surface (m)
bin1utm	4051084	36.600	-34.262
bin2utm	4052215	36.610	-34.216
bin3utm	4053335	36.620	-34.201
bin4utm	4054455	36.630	-34.184
bin5utm	4055564	36.640	-34.193
bin6utm	4056684	36.650	-34.170
bin8utm	4058914	36.670	-34.140
bin9utm	4060023	36.680	-34.132
bin10utm	4061144	36.690	-34.094
bin11utm	4062253	36.700	-34.080
bin12utm	4063362	36.710	-34.064
bin13utm	4064472	36.720	-34.044
bin14utm	4065581	36.730	-34.021
bin15utm	4066690	36.740	-33.995
bin16utm	4067811	36.750	-33.939
bin17utm	4068920	36.760	-33.910
bin18utm	4070030	36.770	-33.879
bin19utm	4071139	36.780	-33.847
bin20utm	4072260	36.790	-33.786

Table 1. Global Geopotential Surface values

C. SYNTHETIC TESTS TO ASSESS ARCVIEW'S SPATIAL ANALYST TOOLS

A synthetic data set was created to assess how effectively ArcView's spatial analysis tools interpret the LIDAR data. A 1000 m by 1000 m region was devised with elevation sampled every 1 m. The spatial units are in Universal Transverse Mercatur (UTM) coordinates, easting and northing units. For the years 1997 and 1998, simulated data sets were then created. The simulated 1997 data set was developed with a beach shoreline along the 600740 easting. From the shoreline, a 45° beach slope was extended inland 300 m then the elevation levels to 300 m. Additionally, a building with an area of 200 m by 200 m was placed at 400 m to 600 m inland with a height of 150 m. The simulated 1997 data set is shown in Figure 11. The data for 1998 were simulated for 2 different cases. The first case simulated a removed building. The volume of the building is 6,000,000 m^3. The simulated data set for case 1 is shown in Figure 12. The second case simulated a recessed beach with the building plunging (removed) into the water.

From the shoreline to 300 m inland, the beach is now submersed and the slope of the beach moves to 300 m inland. The simulated data set for case 2 is shown in Figure 13.

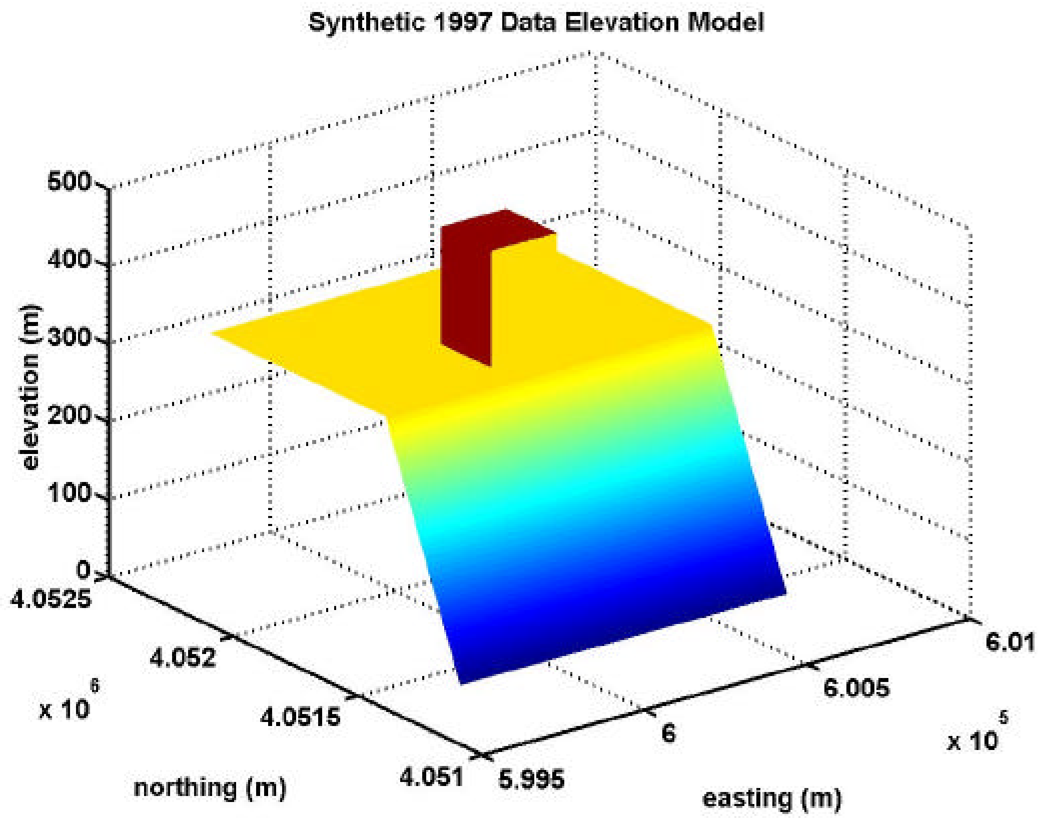

Figure 11. Synthetic 1997 Data Elevation Model

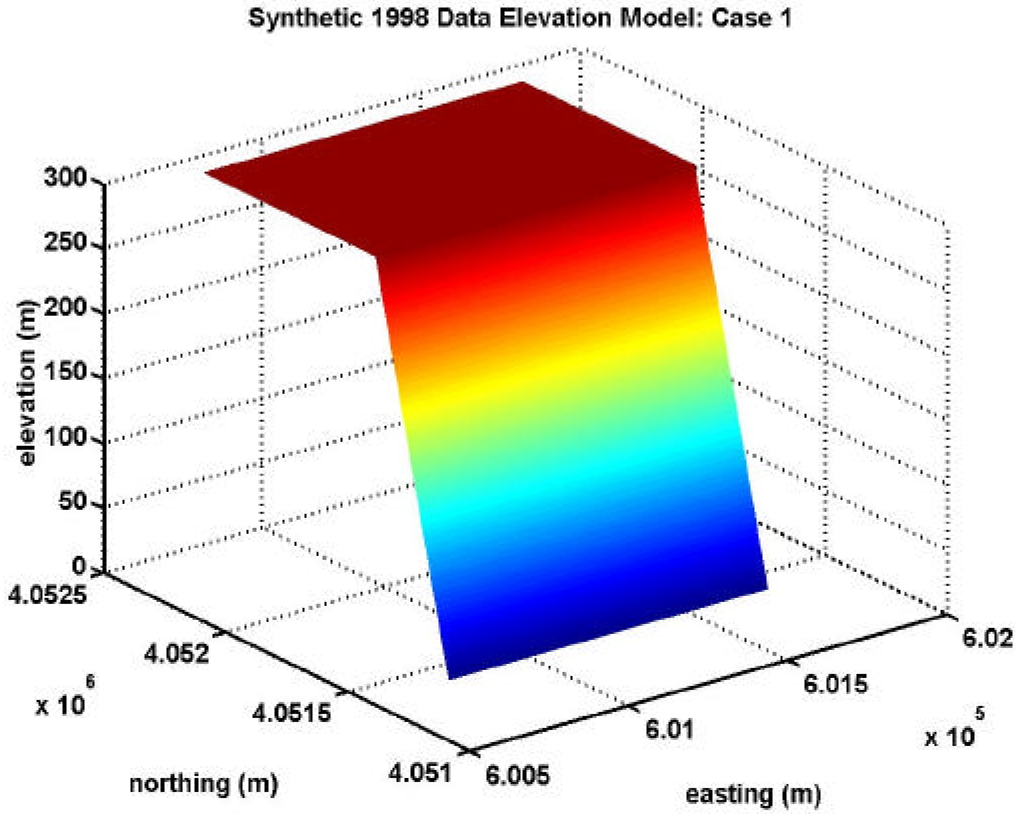

Figure 12. Synthetic 1998 Data Elevation Model: Case 1

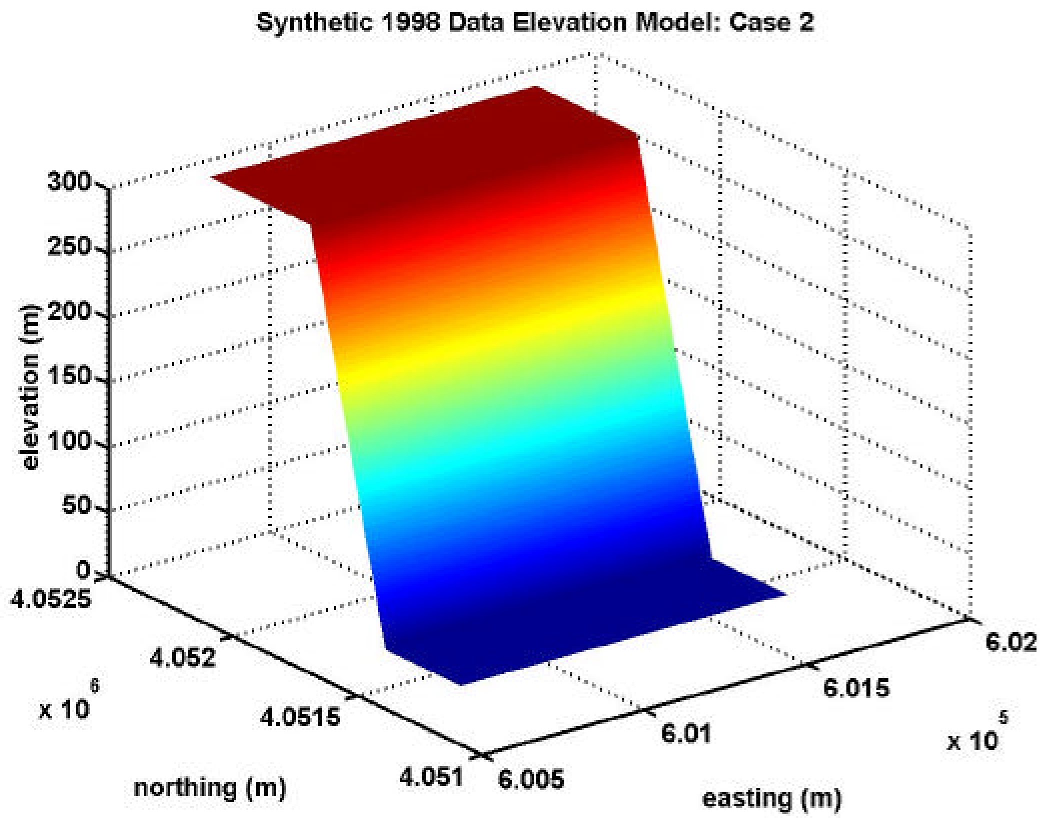

Figure 13. Synthetic 1998 Data Elevation Model: Case 2

The first objective of the synthetic data tests was to assess Arcview surface linear interpolation methods that create Grids and TIN's (Triangulated Irregular Networks). ArcView is geographic information system software developed by Environmental Systems Research Institute (ESRI 2002). When creating a grid in ArcView, the elevation data points are weighted according to the nearest cell that is being analyzed referred to as inverse distance weighting (IDW). The IDW estimation of G(x,y) is given by (Watson and Philip 1985).

$$G(x, y) = \sum_i w_i \, f(x_i, y_i)$$

where w is the weighting , p is the power parameter and d is the distance.

$$w_i = \frac{d_i^{-p}}{\sum_j d_j^{-p}}$$

The power parameter associated with this method controls the weight of the nearby points. A higher power gives less influence to the more distant points. The

assumption for this method is that each elevation data point has a local influence that reduces with distance. The choice of the neighborhood search scheme is key to representing a surface correctly. ArcView uses "kings rule", meaning it looks at the cells above and below (ESRI 2002). Philip and Watson (1982) point out IDW is not ridge preserving, but note improved results can be obtained if there is sufficient sampling. The power parameter (p) of 2 and 12 nearest neighbors (i) were used for this study.

TIN's created in ArcView applies the Delaunay triangulation method. The spatial interpolation on a TIN is linear that assumes a constant slope between two vertices. A process to handle irregularly spaced and complex relief elevation data are the main advantages of TIN's (Burrough and McDonnel 1998, Yue-Hong Chou 1997). Triangulation is described as an accurate technique to represent a surface with no initial approximation of the data points (Philip and Watson 1982). TINs are represented as plane triangular surfaces. The orientation is determined by the elevation then fitted to each triangle. The interpolation occurs down the edges of the triangle between the data points. When the terrain is complex, interpolation can become ambiguous. Therefore, to characterize the surface accurately, more data is required allowing areas of complex relief to be represented.

Cross profile plots were used to assess the surface representation. (See Figure 14) The ArcScript used for the cross profiling was written by Ianko Tchoukanski (2001). Both the TIN and grid provide a good depiction of the data; they both handle sloping surfaces and appear to handle abrupt changes in height. When sampling elevation from the grid and TIN, the elevations values were highly accurate for the TIN and for the grid the average difference in elevation from the true was 0.0632 m. To illustrate how each method represents the surface refer to Figures 14-18. Additionally, a profile from the LIDAR data was performed over Stillwell Hall in Fort Ord to examine how it handles rapid height changes (Figure 19), ArcView was able to distinguish the irregular roof and chimney. Some differences between the 1997 and 1998 profile are that they were possible offsets causing relatively large difference where steep gradients (vertical walls) occur.

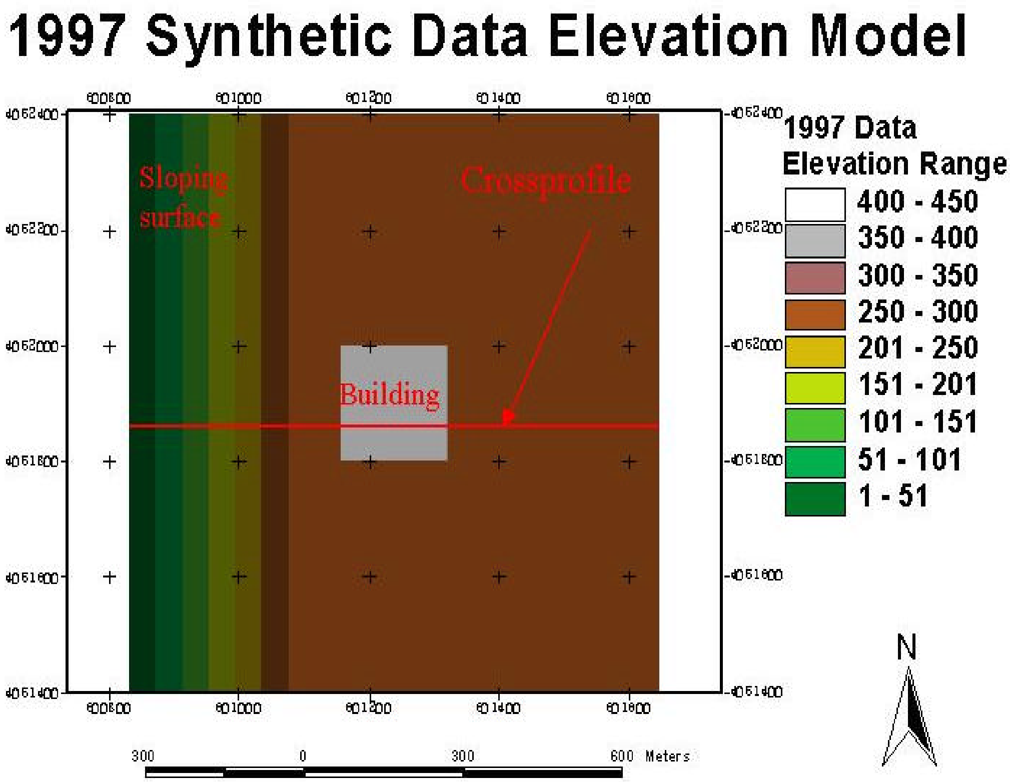

Figure 14. 1997 Synthetic Data Elevation Model

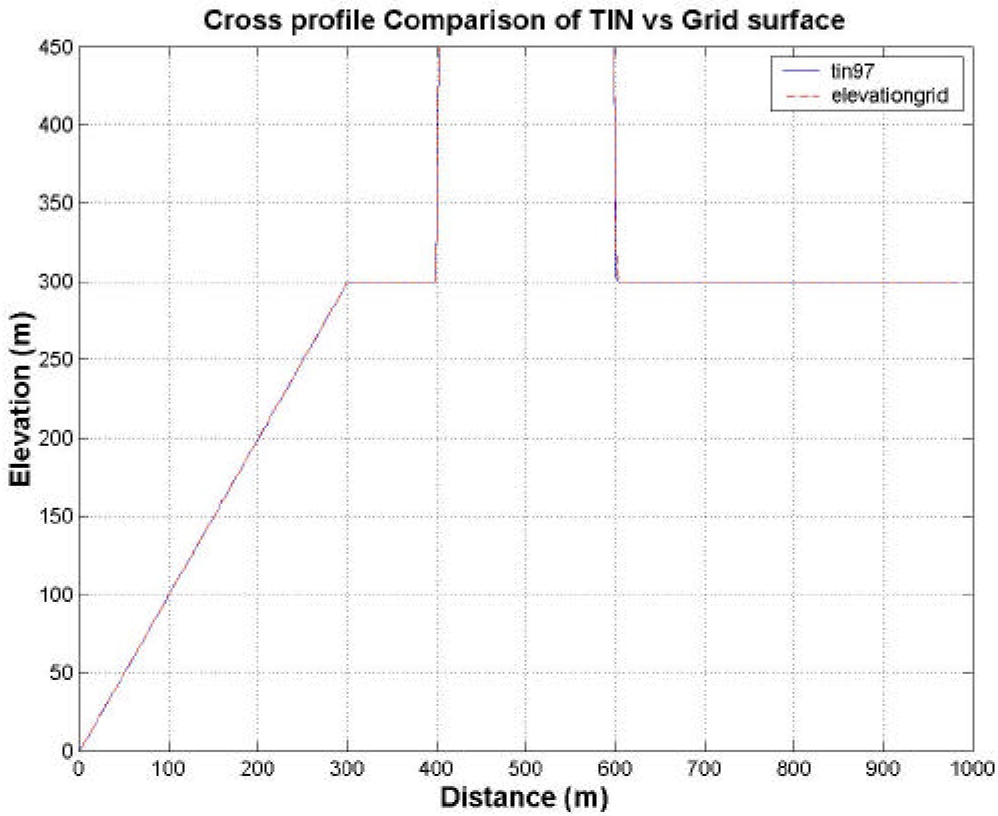

Figure 15. Cross profile Comparison of TIN vs. Grid surface.

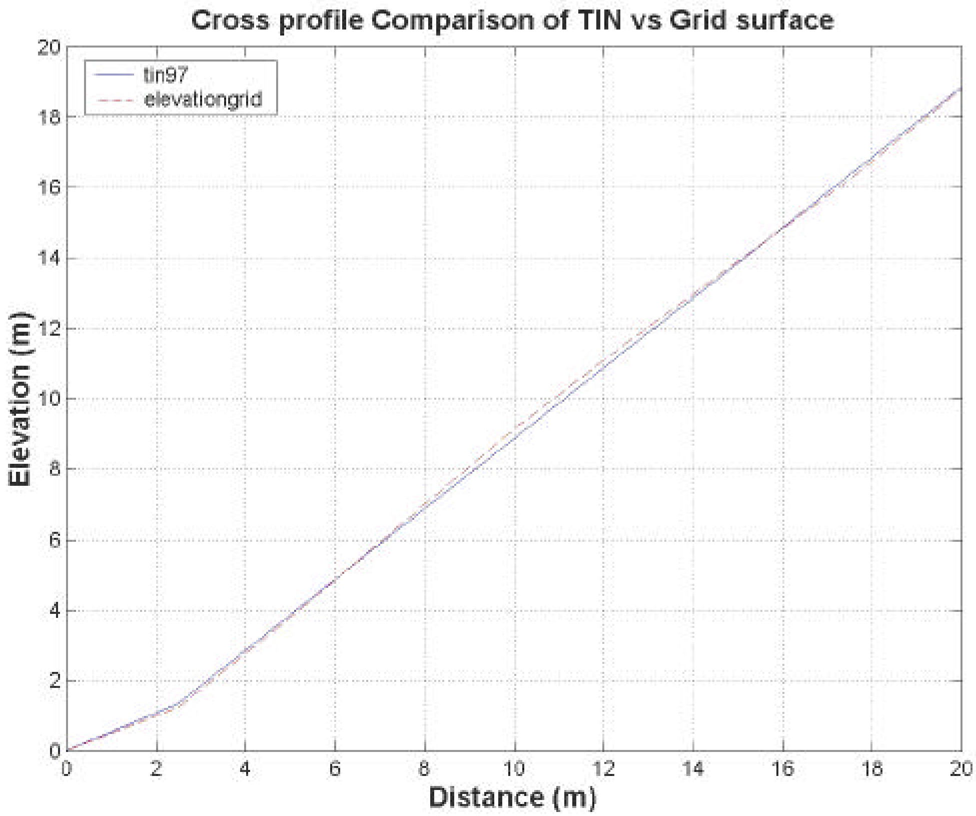

Figure 16. Cross profile Comparison of TIN vs. Grid surface.

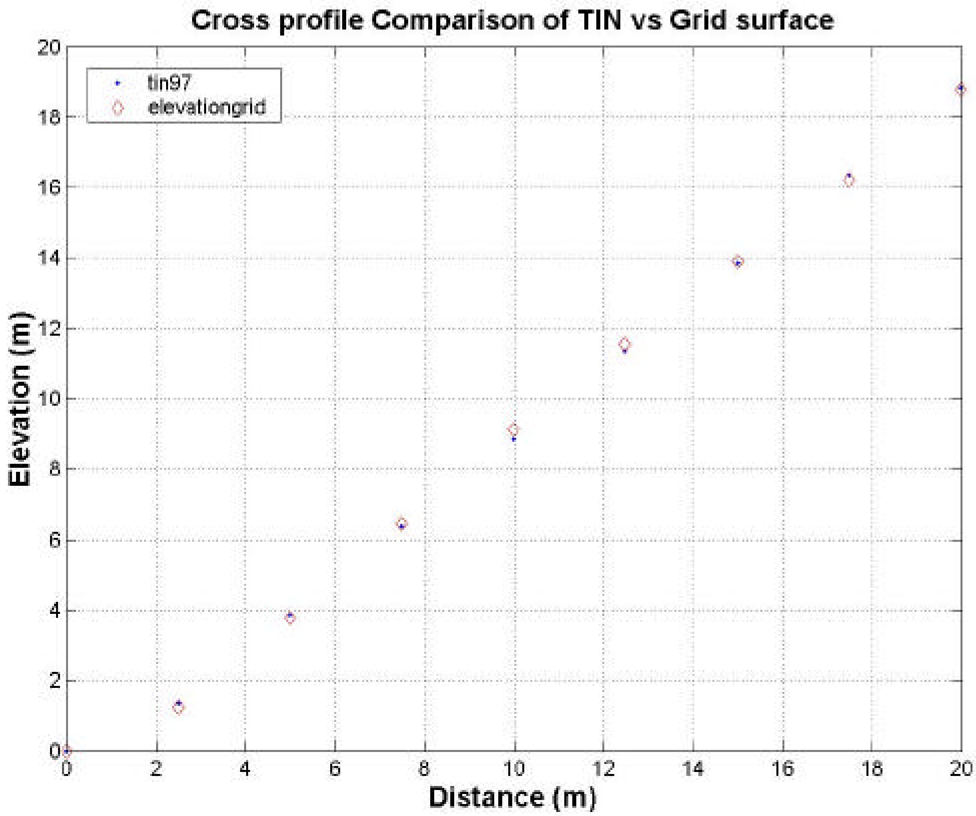

Figure 17. Cross profile Comparison of TIN vs. Grid surface.

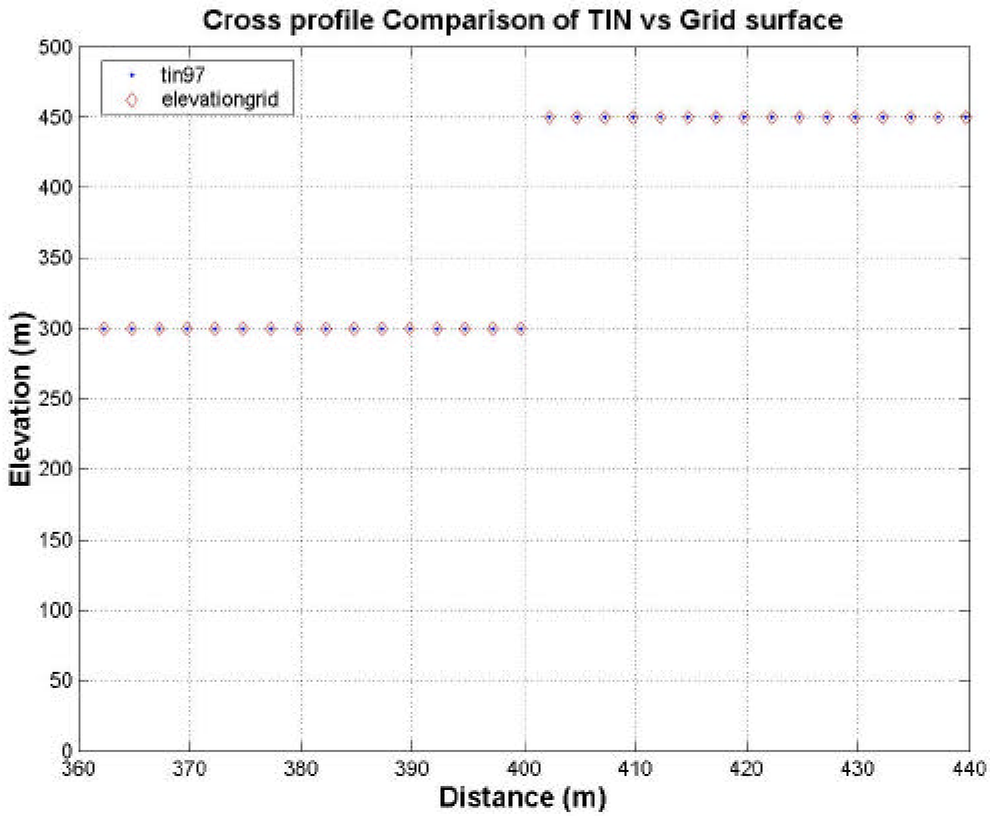

Figure 18. Cross profile Comparison of TIN vs. Grid surface.

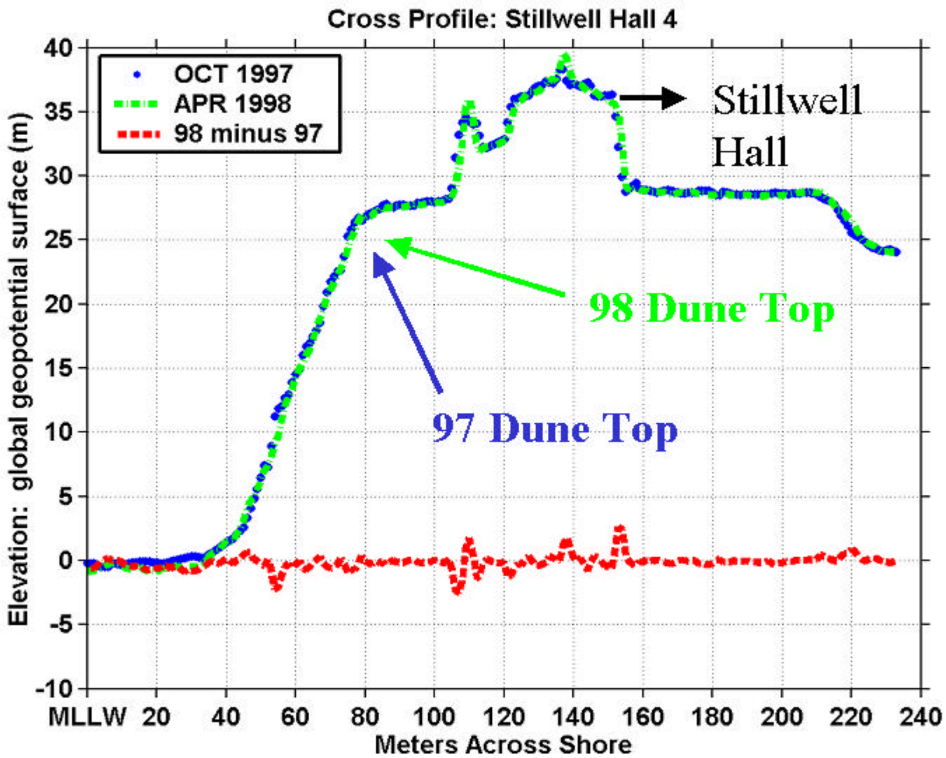

Figure 19. Fort Ord Cross Profile 4

A second objective was to test different grid cell resolutions by comparing 1 m, 1.5 m, and 2 m cell size. Decreasing the cell size improves the data representation, as expected when the cell grid size approached the resolution of the data. The third objective was to compare sampling interval. The real LIDAR 1997-1998 data sampling ranges from 1 m up to 5 m sampling and is not evenly spaced. There were more passes over the region in 1998 than in 1997, which for the most part the sampling distance is 1 m to 2 m, but there are some areas up to 5 m. Gaps were eliminated or minimized by using the edit mask as a control. The synthetic data is evenly spaced every 1 m. It was then sampled at 2.5 m and at 5 m. As the sampling distance increases, the less smooth the representation becomes expected. The 2.5 m and the 5 m sampling depicts the building, but because the sampled interval did not fall on the edge of the building. The edge ended up being within 1 m from the true edge for the 2.5 sampling and within 2.5 m of the edge for the 5 m sampling. Therefore, the closer the sampling interval is to the resolution, the more accurately a feature can be resolved.

Another objective was to test the Cut-Fill option within ArcView from a TIN surface. This method involved a gridded linear interpolation. From this technique the net volume losses and gains were calculated. For the synthetic data set, the building volume loss was calculated and found to be within +/-0.99% of the actual volume loss.

Results from the tests indicate if you choose the closest grid cell size and sampling interval with respect to the data resolution, the more precise and accurate will be the data representation. The TIN's provide an accurate spatial representation of the surface. Therefore, for this study TIN's were used for the surface cross profiles and volume calculations. Overall the results are only as good as the resolution of the data. A problem with this test was the bias in the evenly spaced data.

D. METHOD

Surface information is organized into a set of triangulated irregular networks (TIN's) enabling the beach to be characterized and classified based on elevation. Slope maps were created to assist in identifying dune tops and were derived directly from the TIN. Grids were used in the elevation difference maps, because TIN's cannot be used for difference calculations. A 1 m sampling and 1 grid cell size were chosen for this paper's analysis. Therefore, an edit mask was created to limit the area of interpolation and to highlight a specific area of interest. This method is essential so that ArcView does not interpolate beyond the bounds of the data. The edit mask was derived by starting with NOAA nautical chart 186585 as the base layer in ArcView. 1997 data points were overlayed on the chart. The borders of the edit mask were etched on the inside of MLLW and just inside of the 1997 data (See Figure 20). Once the data were gridded, difference maps were created by subtracting 1997 LIDAR grid from the 1998 LIDAR grid. These difference maps were used as a qualitative aid in identifying potential high loss and gain regions to run a surface TIN profile across. To supplement the LIDAR data, aerial oblique photos and digital orthophoto quadrangles were used as visual aids to assess beach characteristics qualitatively. Volume gains and losses were also calculated from TIN surfaces.

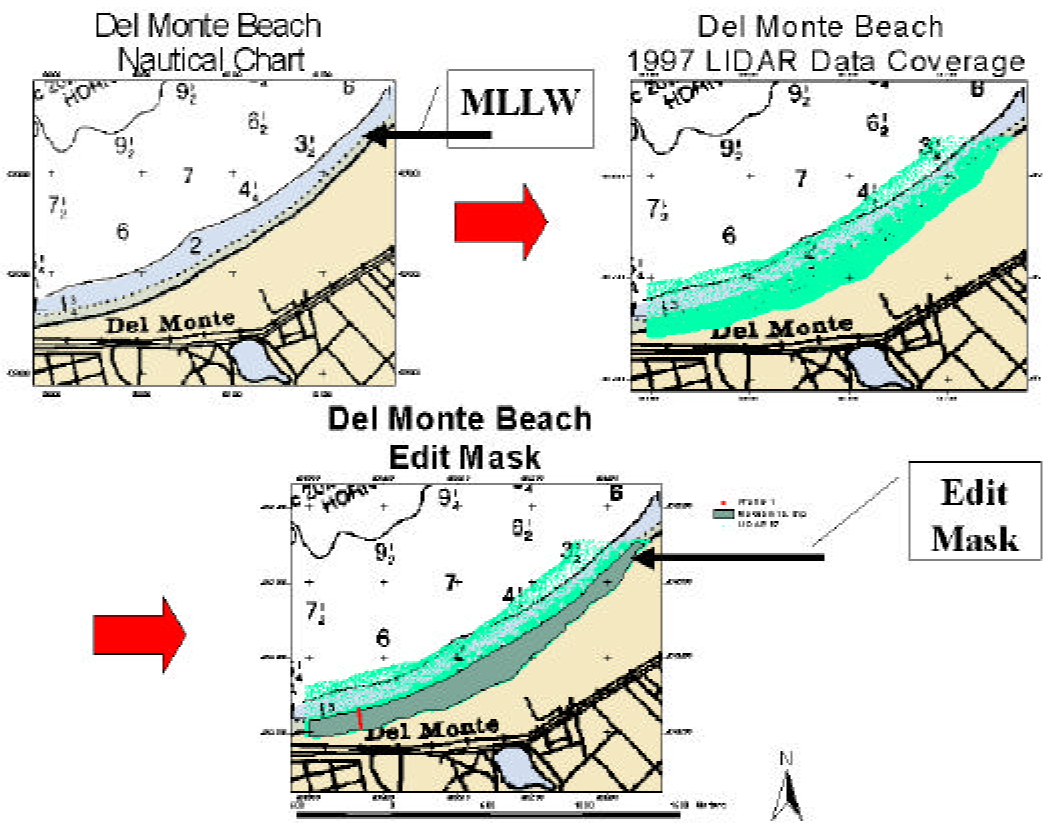

Figure 20. Steps Used to Create Edit Mask

Cross profiles were produced to quantitatively show beach and dune changes in selected regions. The cross profiles were generated from a TIN surface that was sampled every 1 m. Mean lower low water (MLLW) was chosen to start cross profile as the zero line. The MLLW line depicted on the chart with a scale of 1:50000 together with a resultant horizontal ground accuracy of 25.4 m based on the chart scale of 1:50000 and the map accuracy standard.

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III. DUNE EROSION ANALYSIS/RESULTS

LIDAR surveys are used to measure erosion in Southern Monterey Bay. From the LIDAR data, a cross shore profile was generated approximately every 100 m from Monterey to Moss Landing California. Recession is measured as the difference in cross-shore locations of the 1997 and 1998 dune top. The result is a dune recession rate in meters that occurred during the El Niño winter 1997-1998. Negative difference elevation values in the figures below indicate recession, whereas positive values indicate accretion. The nearshore beach morphology is defined in Figure 21 defining off shore bars, berm and dune tops identifying features along the profile (Komar 1998). Details are provided for 3 selected regions and then a summary is given for Southern Monterey Bay.

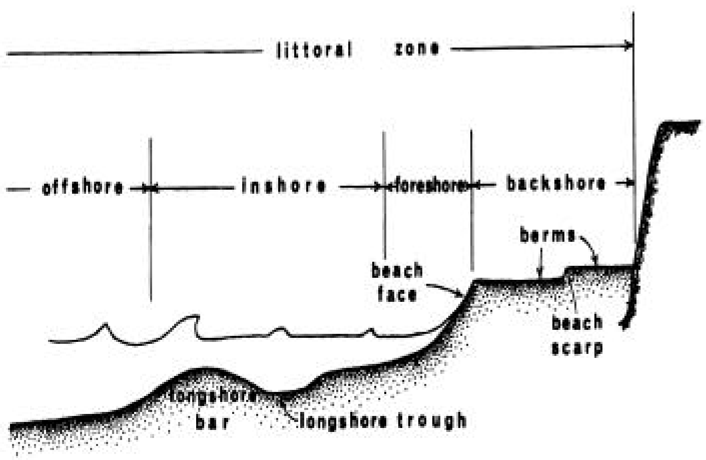

Figure 21. Beach Profile Terminology (from Komar 1998).

A. SELECTED SITES/REGIONS

1. Del Monte Beach

Starting with Del Monte Beach (See Figure 22), a slight 0.5 m to 1 m beach accretion occurred at the south end of the region, which receives the mildest waves owing to the protection of Point Pinos. Following to the north, generally 0.5 m to 1 m of erosion occurs with two "hot spots". The first is in the vicinity of the Navy Beach Lab, where there is an drainage outfall flowing onto the beach, apparently causing 2 m of beach loss. Continuing on, a profile across the Ocean Harbor House reveals 4 m of

recession, which was the loss of sand piled in front of the apartments in the fall of 1997 as a means of beach protection. (Figures 23)

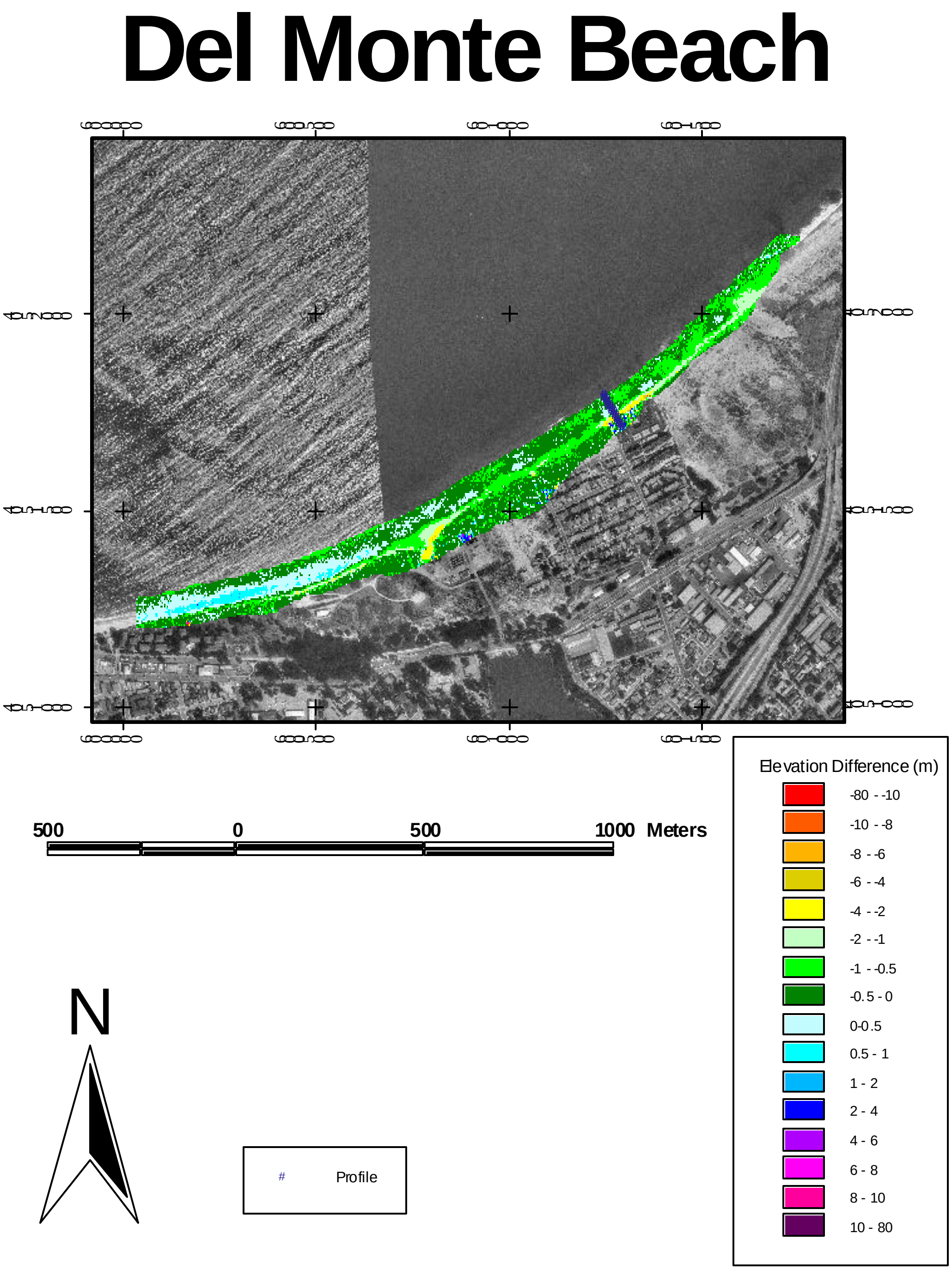

Figure 22. Del Monte Beach: Elevation Difference

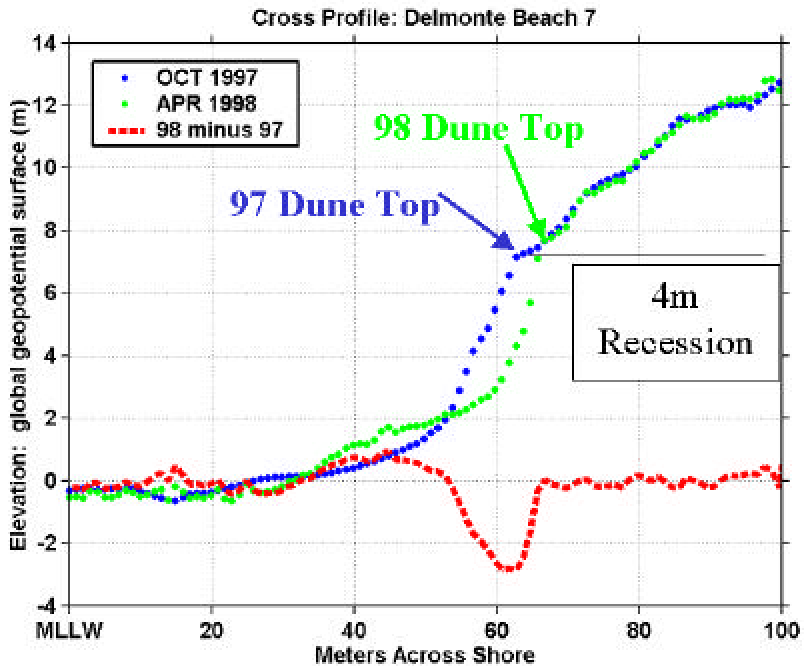

Figure 23. Del Monte Beach: Cross Profile

2. Sand City

Dune recession was highly variable along the Sand City shoreline ranging from no recession to more than 2 m (Figure 24). Up to 4 m in elevation is lost along the beach. There is up to a 1 m increase in elevation in the back dunes (Figure 24). This a location of little dune vegetation, and during high onshore winds, sand often has be removed from Highway 1 opposite profile 3 (Figure 25). The dune is composed of variable material in this location, as the dune between profile 3 and where the road joins (Highway 1 and Del Monte) is the site of the old county dump until 1955. The dune at profile 6 is a site of previous sand mining (Figure 26). Dunes in this region reach up to 50 m.

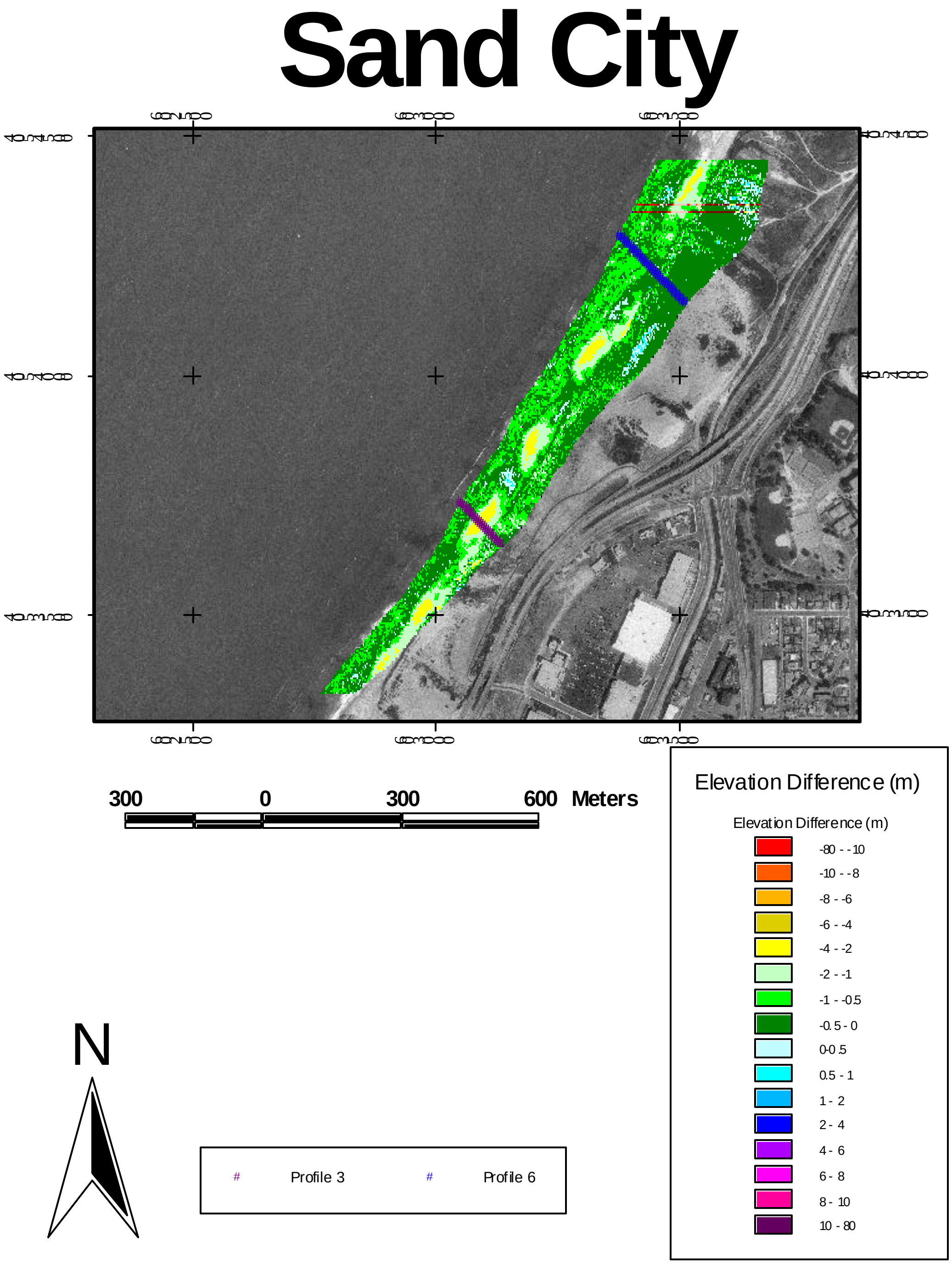

Figure 24. Sand City: Elevation Difference

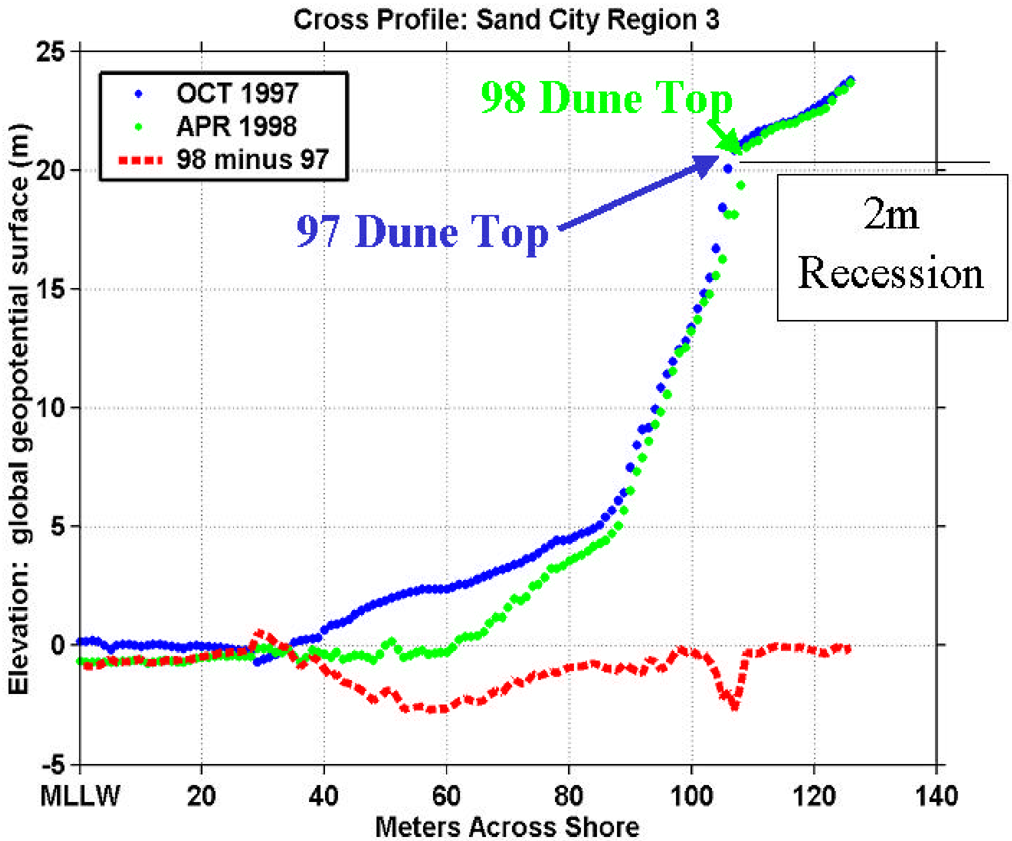

Figure 25. Sand City: Cross Profile 3

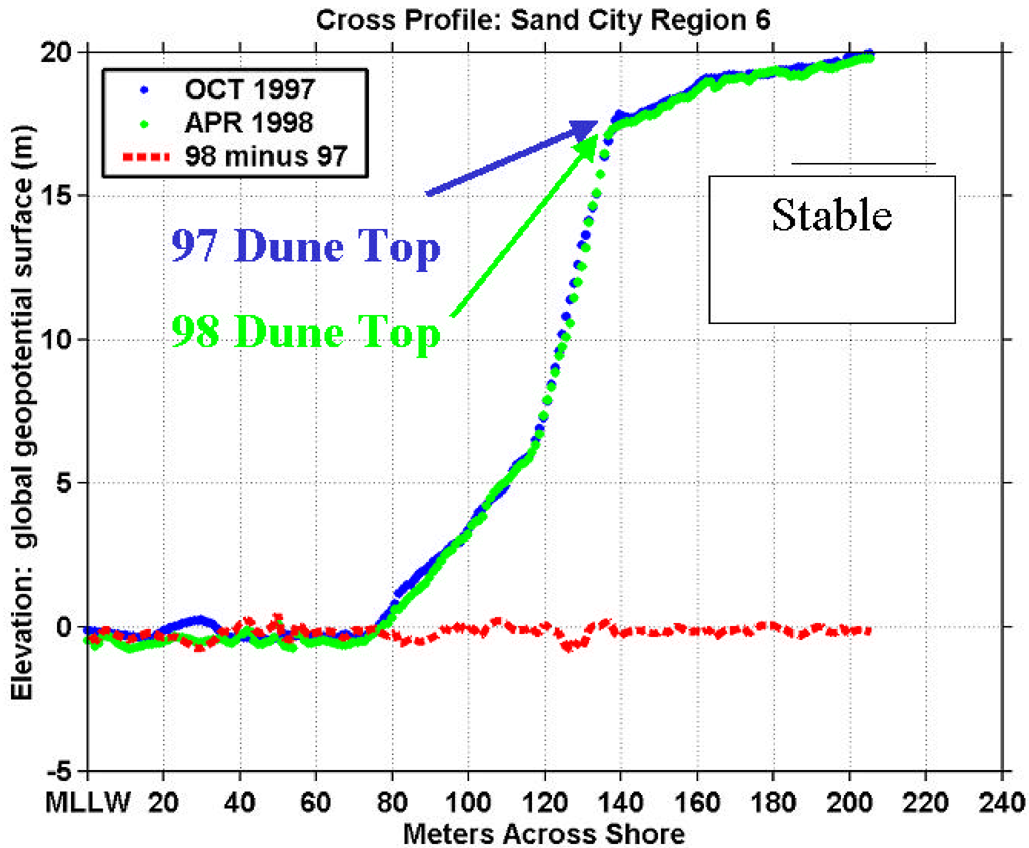

Figure 26. Sand City: Cross Profile 6

3. Fort Ord (Stillwell Hall)

The largest waves impinge on the Fort Ord shoreline as it is more in the center of the bay open to ocean waves and because the predominant northwesterly swells converge here due to refraction over Monterey Bay Canyon (Thornton 2002). The dunes at Fort Ord endure large recession (Thornton 2002). Three profiles north, south and through the center of Stillwell Hall are shown in Figures 27-30. A photo of Stillwell Hall (Figure 31) shows the revetment placed in front stops erosion, but with large recession to each side. The profiles to each side show up to 13 m of recession (Profiles 2 and 6). No recession occurred in front of Stillwell Hall (Profile 4). Dunes in this region extend in elevation up to 46 m.

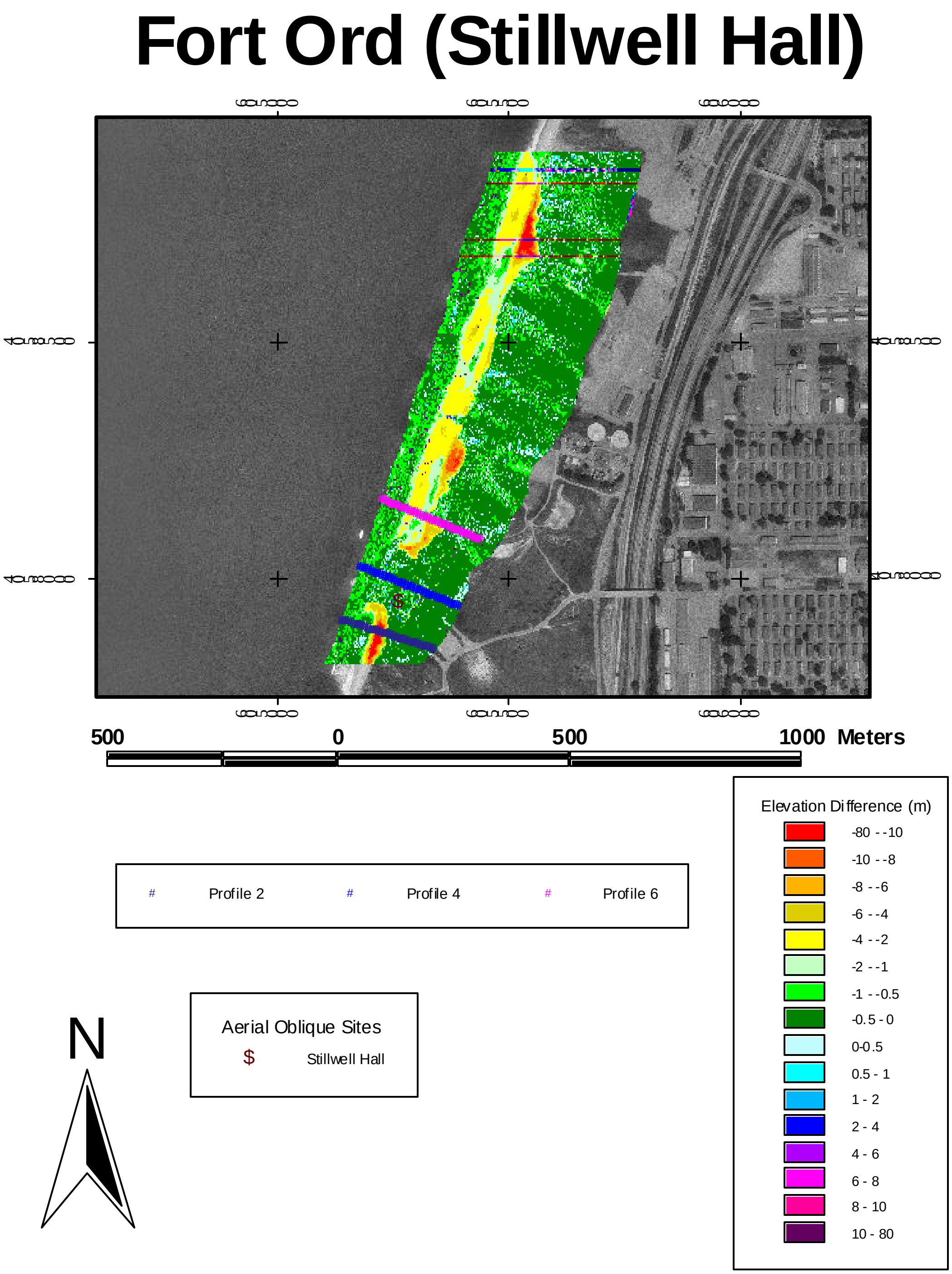

Figure 27. Fort Ord: Elevation Difference

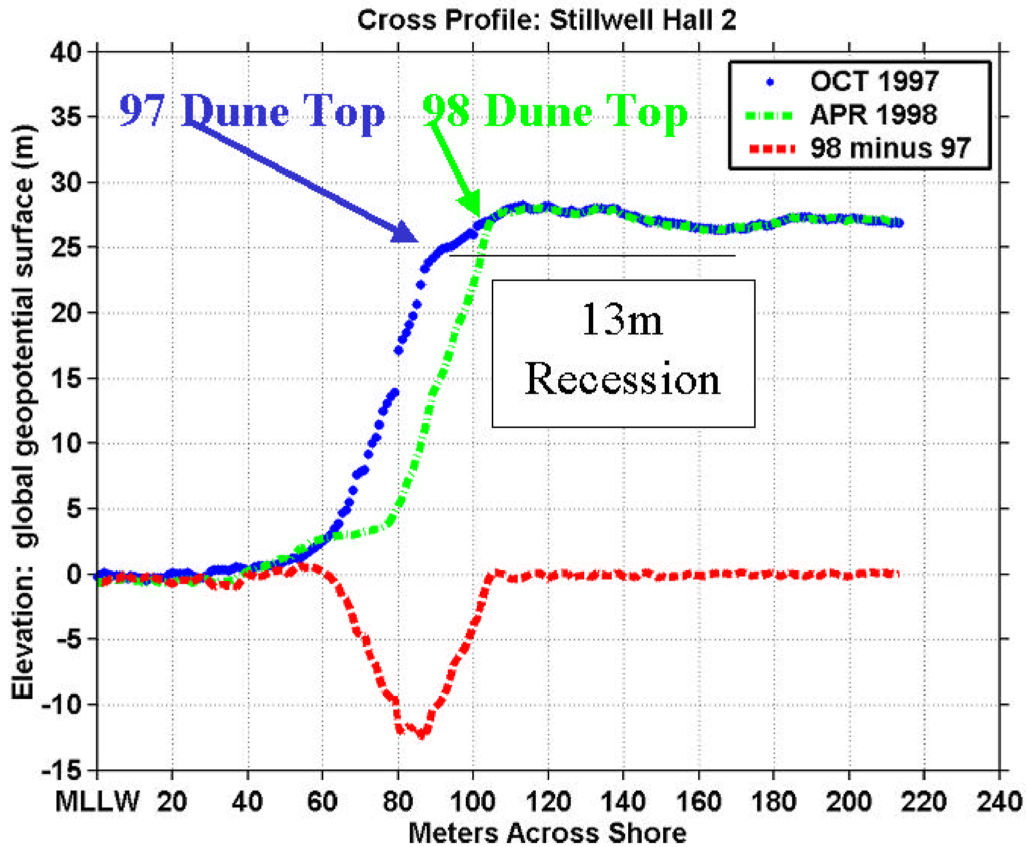

Figure 28. Fort Ord: Cross Profile 2

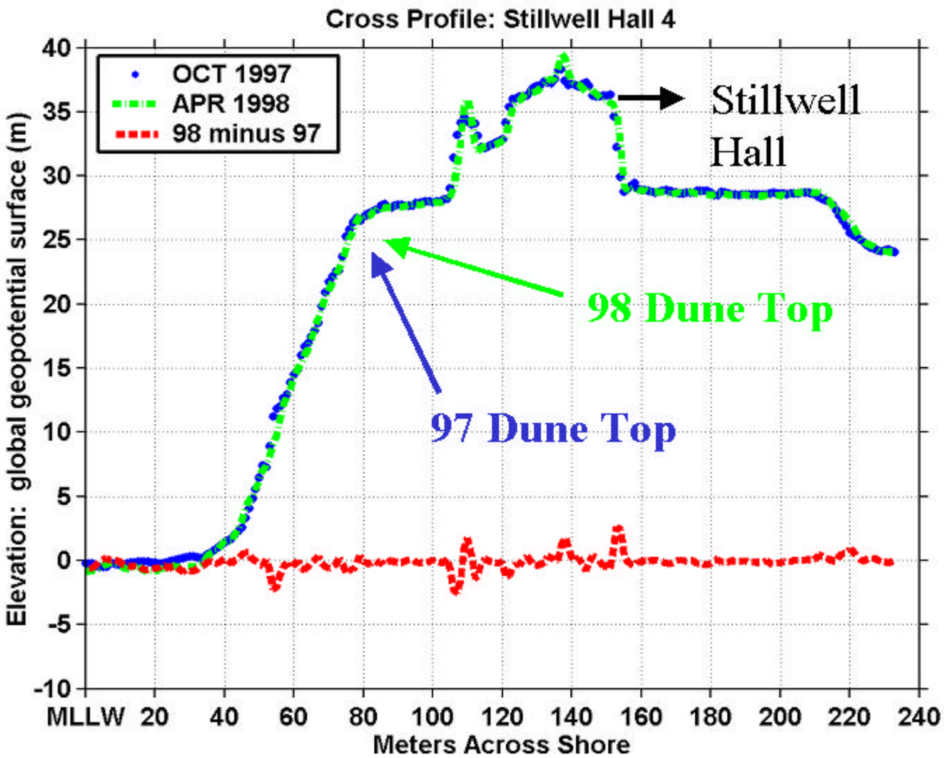

Figure 29. Fort Ord: Cross Profile 4

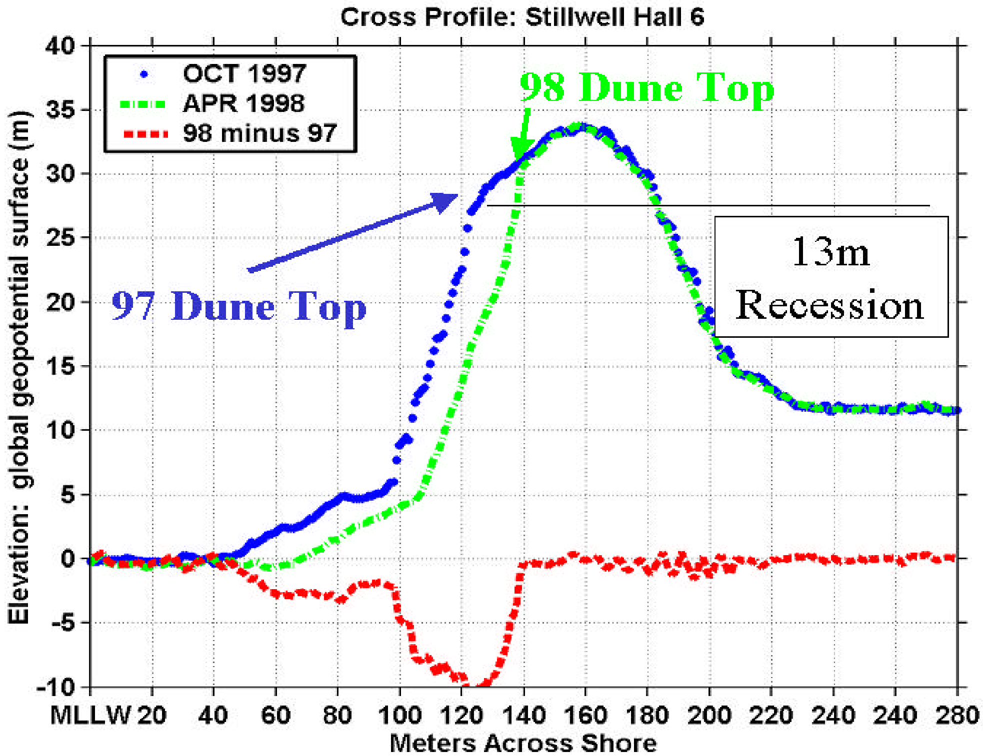

Figure 30. Fort Ord: Cross Profile 6

Figure 31. Fort Ord: Aerial Oblique Photo (from USGS 1998)

B. SUMMARY OF THE SOUTHERN MONTERY BAY

1. Large Variability in Dune Erosion

Erosional patterns are apparent from elevation difference maps (Figure 32). One of the striking observations from the difference maps is that erosion is not uniform, but varies considerably alongshore. Along 23 km of coast, there were areas of accretion, dune erosion, river overwash, manmade losses, beach losses and gains, and indicators of alongshore and cross shore sediment transport.

The measured recession is the difference in dune tops between the two surveys taken from profiles approximately every 100 m alongshore (Figure 33). Recession is significant throughout Monterey, Sand City, Fort Ord and Marina. Monterey losses were up to 4 m. Sand City showed up to a 2 m recession. Fort Ord and Marina had the highest cutbacks of up to 13 m. Moss Landing and the Salinas National Wild Life Refuge showed seasonal beach loss up to a 4 m in elevation. (See Figure 33)

Dune top elevations were measured at each profile. The dune top varies considerably alongshore with elevations up to 9 m in Monterey, 50 m in Sand City, 46 m in Fort Ord, 25 m in Marina, and 7 m in Moss Landing (Figure 34).

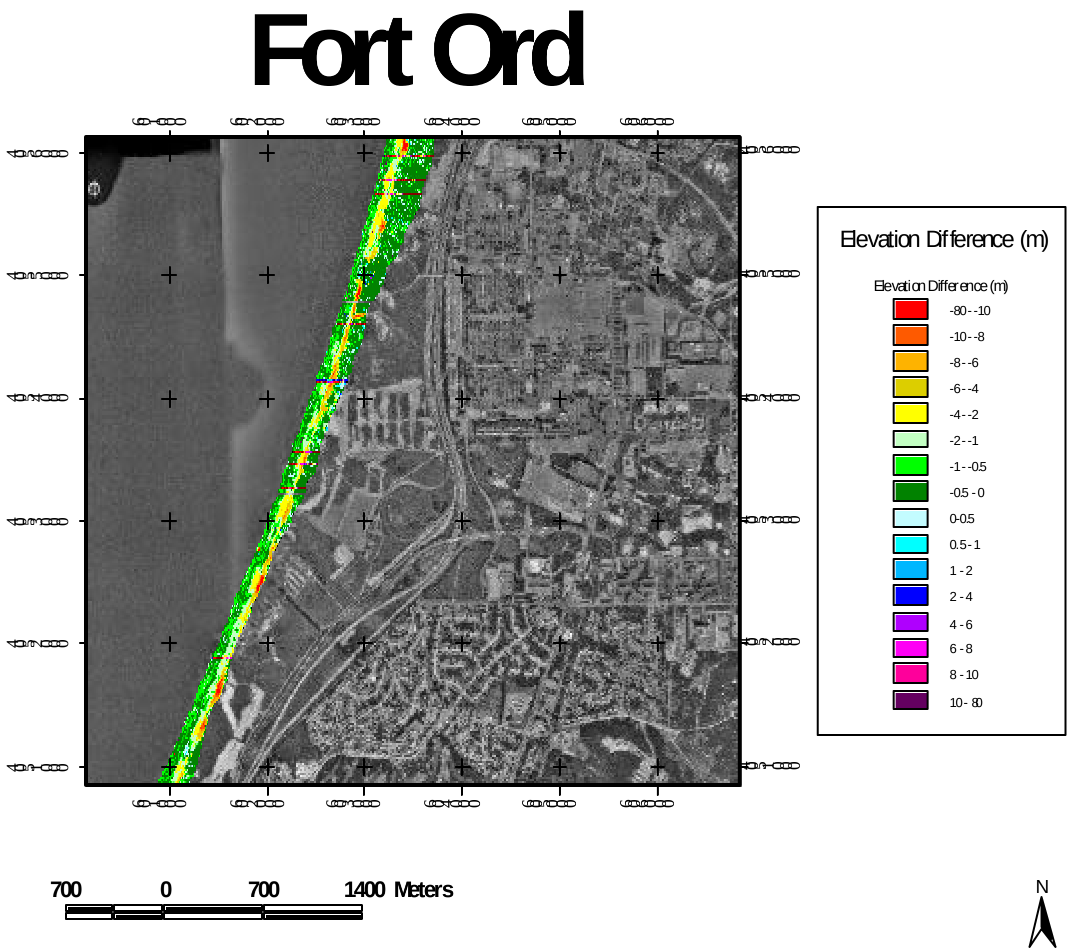

Figure 32. Fort Ord Elevation Difference

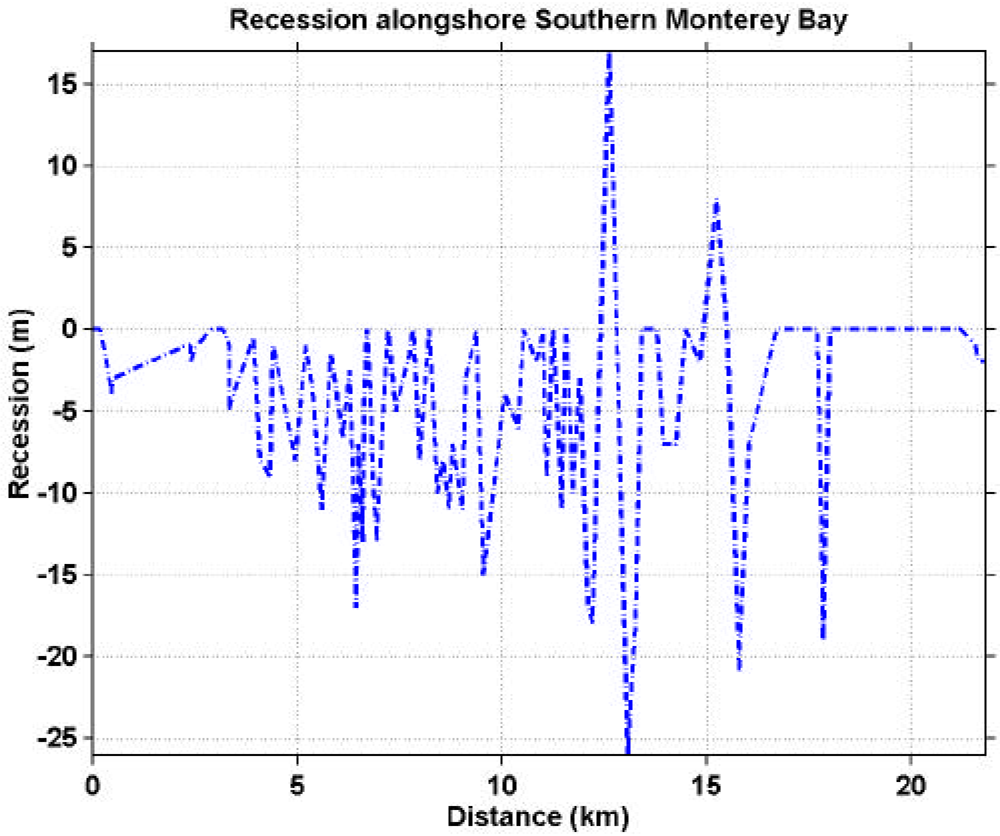

Figure 33. Recession Alongshore Southern Monterey Bay

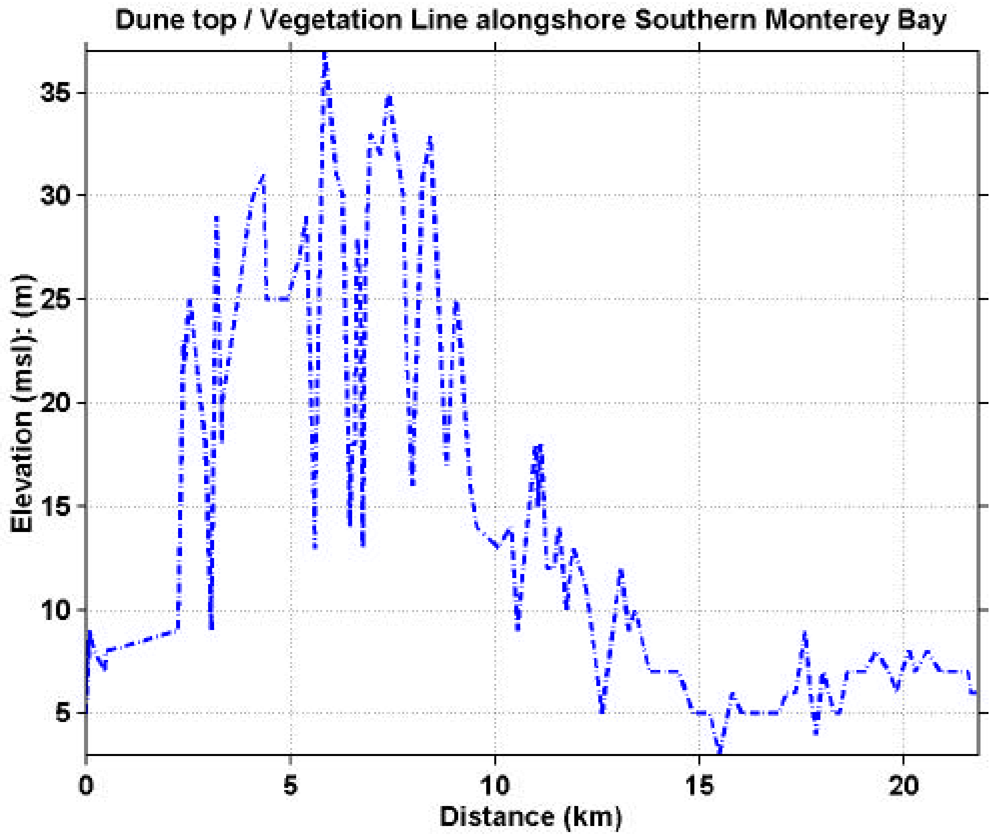

Figure 34. Dune Top / Vegetation Line Alongshore Southern Monterey Bay

The dune erosion occurring between October 1997 and April 1998 can be estimated by multiplying the recession of the dune top by the height of the dune. Examinations of the profiles throughout Southern Monterey Bay (for example Figures 25, 28 and 30) show the toe of the dune at approximately +5 m above MSL. This suggests that dune erosion only occurs during extreme run-up by storm wave coincident with high tides cutting at the toe of the dune. The profiles suggest that changes in profiles below +5 m are associated with changes in the beach profile, which are seasonal. Therefore, the dune erosion is calculated subtracting 5 m from the height of the dune. The erosion (accretion) of the dune is alongshore is shown in Figure 35. The total dune erosion is obtained in integrating the erosion alongshore and equals 880,000 cubic meters for this El Niño winter.

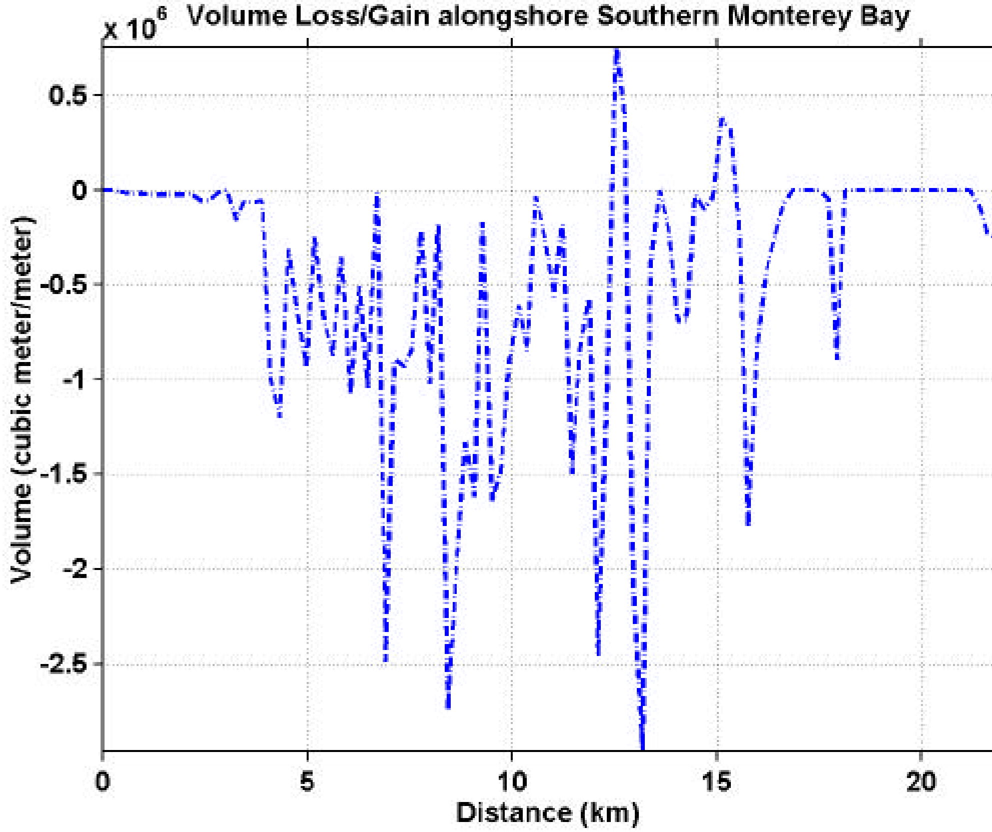

Figure 35. Volume Loss/Gain Alongshore Southern Monterey Bay

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IV. DISCUSSION

A. EROSION RESULTS

The total change in volume of the dunes and beaches using the cut-fill calculations within ArcView to measure the difference between the 1998 and 1997 images for each 19 increments along the approximately 22 km of shoreline was 3,423,700 m^3. This amount of sand is viewed as a contribution to the sand budget. The erosion and accretion were measured separately. Some accretion occurred on the beaches at various locations and on the dunes presumably due to sand blow shoreward by the prevailing wind. The total erosion was 3,590,300 m^3 compared with the total accretion of, 166,600 m^3. The accretion of sand on the dunes is viewed as a loss in the sand budget. A previous study of cliff erosion using stereo-photogrammetric methods from photos from 1944 to 1987 found the average annual erosion for Southern Monterey Bay from Monterey to the Salinas River (18 km) was 350,000 cubic yards (267,600 m^3). The total volume loss (total erosion minus total accretion) calculated for this study was 3,423,700 m^3. Using MLLW line as the edge of area for these calculations provides for error is estimated to be 950,000 m^3(sand area / volume routinely exposed to wave action). When this error is subtracted, the volume loss becomes 2,470,000 m^3.

The measured cliff top erosion was obtained by multiplying the cliff top recession times the height from the toe to the top of the cliff, which gives a result of total volume loss of 880,800 m^3cubic meters. The difference between contributions to the sand budget by cliff erosion and the total erosion is a measure of seasonal change in the beach profile. It is assumed the sand goes offshore to form a bar and eventually returns with the summer swell waves, but also with some permanent loss to the offshore.

The scope was to identify dune top and quantify recession or accretion with emphasis on examining and comparing previous surveyed areas. There were certain limitations regarding the 1997 data set. The LIDAR 1997 coverage was much less than the 1998 data. In particular, Sand City could not be thoroughly examined due to scarce coverage in 1997. Also, some of the 1997 data did not extend far enough inland to attain

the dune top. Sediment budget, long term erosion trends, wave data and cessation of Sand City's mining were not assessed.

B. RECOMMENDATIONS

There are numerous additional avenues to pursue from this LIDAR research project. Specifically one could examine a LIDAR storm year versus a LIDAR normal year. Secondly, the possibility to develop a sediment budget using ArcView tools to calculate volume losses and gains is approachable. Thirdly, it would be beneficial to correlate the erosion with physical parameters such as wave energy, tides, beach sediment grain size and other environmental parameters to better understand erosion processes.

V. CONCLUSIONS

Erosion appears to be highly episodic. The wave climate for Southern Monterey Bay during period 1987-1997 was relatively calm wave climate for Southern Monterey Bay with little to no erosion occurring. The 1997-1998 El Niño winter was a time of high tides, storminess, and wave energy resulting in significant erosion. Large cutbacks in Fort Ord and Marina occurred, as well as significant recession in Monterey and Sand City. Starting from the south, recessions at Monterey ranged from 0 m to 4 m. Sand City recession ranged from 0 m to 2 m. It is noted that there was insufficient LIDAR coverage for approximately a kilometer of the shoreline in Sand City; therefore Sand City was not assessed entirely. Fort Ord had large cuts ranging from 0.5 m to 13 m. Drainage cuts were also present up to 17 m. Marina had the largest dune recession of 15 m. Marina's recession range was 0 m to 15 m. It was sometimes difficult to identify dune tops, particularly at Moss Landing where it became more subjective and concluded there was little recession, just beach loss ranging from 1 m to 3 m. There was also some sediment accretion present. In particular, deposition around the Salinas River was evident as well as the overwash that occurred. The pattern of the beach profiles indicated seasonal change and indicated cross-shore sediment transport. Manmade sand deposits were also obvious along Del Monte Beach and just north of Marina.

Erosion did not occur uniformly showing large spatial variability all along the shoreline, with many observed erosion "hot spots". The scale of the alongshore variability varied between 100 m to 1 km.

With respect to Navy applications, ATM LIDAR can provide significant environmental information to operational units in regards to beach characterization. The elevation detail that LIDAR provides can be an invaluable aid in planning amphibious landings or Special Operations providing intelligence on landing zones, ingress/egress routes based on slope as well as dimension of man-made impediments.

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